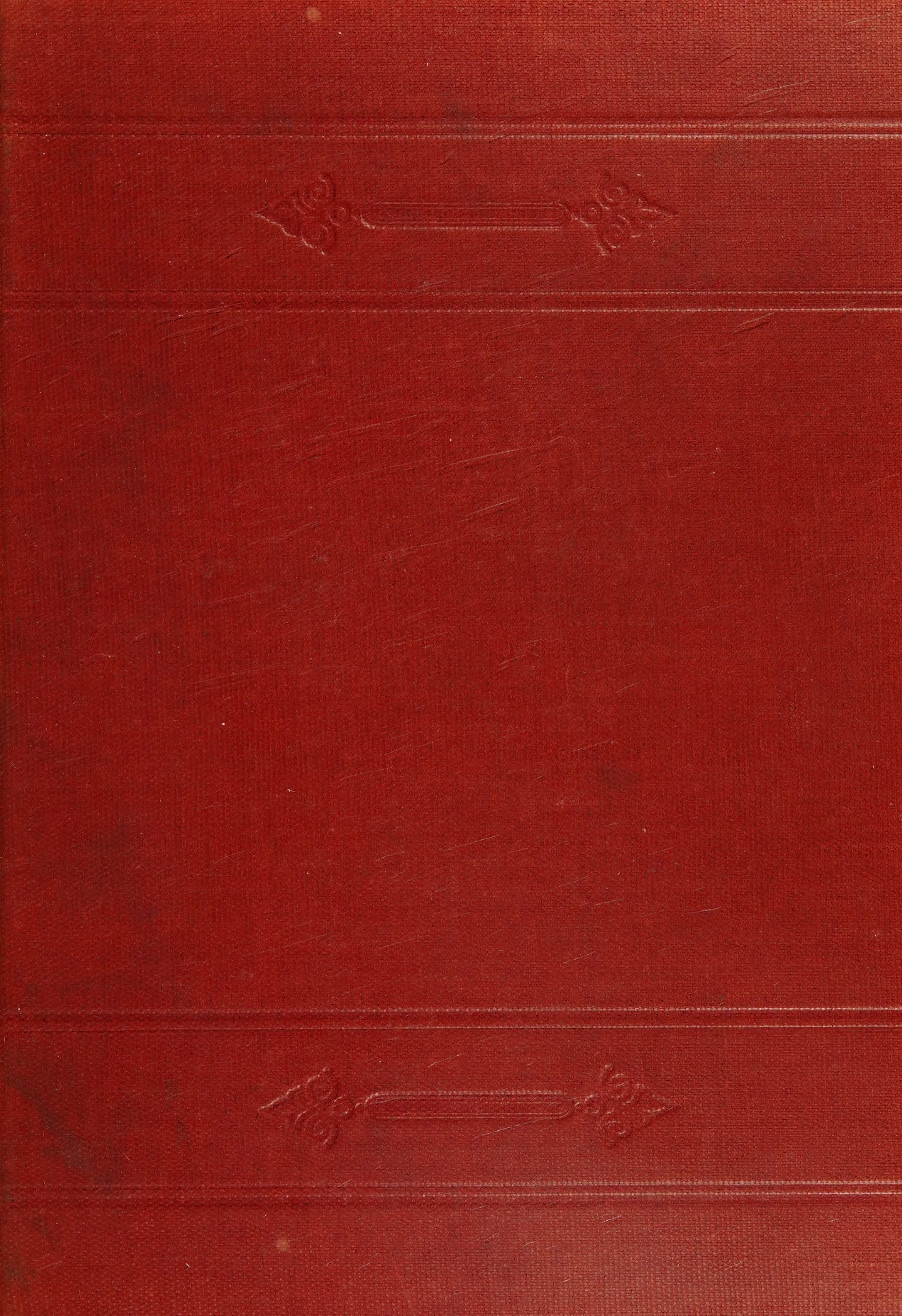

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ERRATA

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Page 147, fourth paragraph, last line: *Figure 5* should be *Figure 3.*

Page 247, twenty-seventh line: (*0.6 foot* should read (*0.6 foot*).

Page 275, third line of legend under Figure 2: *Lonella* should read *Louella.*

Page 383, contents, under anchovies: Distribution of young should be *394* instead of *384.*

Page 401, first line: *as its range in size* should read *as its range in diameter.*

Page 569, contents, second column, third line from bottom: *biology for conversation* should read *biology for conservation.*

MIGRATIONS AND OTHER PHASES IN THE LIFE HISTORY OF THE COD OFF SOUTHERN NEW ENGLAND

⁂

By WILLIAM C. SCHROEDER

Assistant Aquatic Biologist, United States Bureau of Fisheries

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INTRODUCTION

The cod is one of the most valuable and best known of all fishes. In the western Atlantic it has been caught from as far north as latitude 67° on the west coast of Greenland (Jensen, 1926, p. 89) to as far south as Cape Hatteras, N. C., and in European waters from Spitzbergen to the region just southwest of Great Britain. A few stragglers enter the Bay of Biscay. Along our coast the most southerly ground where cod are to be found in commercial numbers the year round is off southern Massachusetts, and it is only from November to May when, by migrating, they invade the region extending from Rhode Island to North Carolina. No commercial fishing for cod has been carried on south of Delaware.

The cod has been of great economic importance to North America from the time of the earliest white settlers to the present era. Sette (1927, p. 3) points out that its fishery is probably the most international of any off North America, as no less than five nations take part in it.

During the 30-year period from 1896 to 1925 the annual catch of cod off the east coast of North America has ranged from 872,000,000 to 1,339,000,000 pounds, with an average of 1,103,000,000. Although subject to fluctuations, the general productivity of the cod fishery neither increased nor decreased during this time. The catch for the past 30 years has been divided among the five nations concerned, as follows: Newfoundland, 49 per cent; Canada, 20 per cent; France, 17 per cent; United States, 12 per cent; and Portugal, 2 per cent. (Sette, 1927, p. 13.) In the eastern Atlantic the annual catch of cod amounts to about a billion pounds.

The cod held first rank in the New England vessel fisheries for many years, but recently with the increasing number of otter trawlers and the improved methods of preparing and marketing fillets, the haddock has assumed first place. The landings of cod at Boston, Gloucester, and Portland, expressed in terms of fresh fish, amounted to 67,098,688 pounds, valued at $2,184,141, during 1923;[1] 64,241,619 pounds, valued at $2,138,306, during 1924;[2] 82,586,677 pounds, valued at $2,644,582, in 1926;[3] and 65,342,013 pounds, valued at $2,146,503, in 1927.[4]

Europeans as well as Americans have studied its spawning habits, and each year millions of young cod are artificially hatched and liberated. The cod's preference for certain foods has become known by investigators, who have examined thousands of stomachs. Statistics have been compiled from year to year on the amounts of cod and other fish landed at the important markets along the Atlantic coast and the amounts taken on each of the important fishing banks. Yet, in spite of all the study that has been devoted to the cod, there are still serious gaps in our knowledge of its life history.

That bodies of cod move from place to place has long been known by fishermen. We are reasonably certain that they carry out breeding migrations, for large schools of fish are found in certain localities only during the spawning period. It is probable, too, that bodies of fish move about in search of good feeding grounds, and that they make some effort to avoid extremes of temperature which are unfavorable to them. In general, the smaller fish are the more stationary while the larger are the more migratory. Besides the schools of fish which appear to travel en masse, some individuals, usually the larger fish, seem to lead a nomadic existence. But even these may not migrate far in any given direction if we take tagged fish as a criterion.

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[1] Fishery Industries of the United States for 1923, U. S. Bureau of Fisheries.

[2] Ibid. for 1924.

[3] Ibid. for 1926.

[4] Ibid. for 1927.

In Europe the cod has been studied by means of marking experiments for more than 25 years, while in American waters, prior to the present experiment, one was made off Woods Hole, Mass. Although marking experiments have thrown considerable light on the behavior of the cod in European waters, particularly on their migrations, we can not assume that the same conditions obtain along our coast or that the habits of American and European cod are similar in all respects.

The present investigation was undertaken on April 17, 1923, to study the cod's life history not only as a matter of biological interest but so that if a decided decline in the abundance of the fish should ever occur the fishing industry would be able to adjust itself thereto with as full a knowledge as possible of the fish's habits, especially of its migrations, duration of life, rate of growth, and size at different ages. The present study concerns the natural history of the cod after it seeks bottom, including fish as small as about 2 inches in length.[5] Most of the field work during 1923–1925 was carried out by means of the Bureau of Fisheries' vessel *Halcyon*, commanded by G. W. Carlson. A few fish were tagged by the steamer *Fish Hawk*, while specimens and data were collected by the steamer *Gannet*. In 1926 the *Halcyon* and *Fish Hawk* were taken out of service, and since that time all investigations have been carried out with the *Albatross II*, together with small fishing boats.

It was realized at the start of this cod investigation that an extensive territory was available for carrying on operations, including both the shore grounds along the entire New England coast and the offshore banks such as Georges, Browns, Sable Island, and the Grand Bank. As the *Halcyon* was not suitable for fishing the offshore banks, operations from 1923 to 1925 were restricted to within about 40 miles of land.

Nantucket Shoals was selected for the first tagging partly for this reason, partly because (*a*) it is the most southerly region along our shores where cod are caught in abundance in the summer; (*b*) there was a strong probability from Smith's (1902) experiment that a migration of cod occurs between Nantucket Shoals and the region from Rhode Island to New Jersey, so that definite results might be expected from the first year's work; (*c*) cod are abundant in water shoal enough to fish conveniently with hand lines; (*d*) boats fish there from time to time; and (*e*) two of the largest offshore fishing banks—South Channel and Georges Bank—are adjacent, thus affording an opportunity for determining migrations of cod to and from Nantucket Shoals.

Opportunity is taken here to thank Dr. Henry B. Bigelow, of Harvard University, for his helpful advice in the preparation of all parts of this paper. Thanks are also extended to O. E. Sette for suggestions, temperature records, and other data, and to R. A. Goffin for specimens of young cod. Acknowledgment is made to Capt. G. W. Carlson of the *Halcyon*, and later of the *Albatross II*, and to the officers of these vessels for their cooperation, which was so necessary in making the field work a success. Finally, I wish to thank fishermen and those connected with the fishing industry for sending tags from recaptured fish and for supplying information on the habits of the cod.

HISTORICAL

COD MIGRATIONS IN EUROPEAN WATERS

The first real attempt to determine the migrations of cod by means of tagging experiments was made in the North Sea off Scotland, in October and November, 1888, when 16 fish were marked with numbered brass labels. (Fulton, 1890, pp.

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[5] Some study has been given to earlier stages by Charles J. Fish: Production and Distribution of Cod Eggs in Massachusetts Bay in 1924 and 1925. Bulletin of the Bureau of Fisheries, Vol. XLIII, 1927 (1928), Pt. II, pp. 253–296.

353–355.) Of these, 3 fish, or 18 per cent, were subsequently recaptured, all of them that same winter and all near where they were tagged. By 1892, around the Firth of Forth, 196 cod had been marked, of which 10, or 5.1 per cent, were subsequently recaught. Fish as small as 7 inches in length were utilized, and only 16 exceeded 20 inches. Most of the recaptures were made locally, the farthest distance away from the point of tagging being 52 miles, and the mean period of freedom being about 75 days. (Fulton, 1893, p. 189.) Further tagging in the North Sea has been recorded by Boreley, Strubberg, Graham, Weigold, and others.

Boreley (1909, pp. 2–3) records the tagging of 252 cod in the North Sea from 1904 to 1907, of which 16.6 per cent were recaptured—32 fish within 6 months after tagging, 8 fish 7 to 12 months later, and 2 fish after 13 to 15 months. Most of the cod were recaptured near the tagging grounds and none were taken outside of the North Sea. Weigold (1913, p. 119) reports returns from North Sea tagged cod as high as 60 per cent—181 recaptures from 301 marked fish, most of them 20 to 39 centimeters long. Nearly all these were recaptured in the vicinity of the tagging grounds.

Strubberg (1922) reports on the marking of cod in Danish waters from 1905 to 1913. Out of a total of 1,547 tagged fish, 338, or about 22 per cent, were subsequently recaptured within the following time intervals: 316 within 1 year, 19 after 13 to 24 months, 2 after 26 to 29 months, and 1 after 47 months. Most of the fish utilized for tagging ranged in length from 25 to 70 centimeters (10 to 28 inches), and most of these were below 50 centimeters (20 inches). A greater proportion of the smaller tagged cod was recaptured than of the larger (25 per cent of 1,170 specimens less than 60 centimeters, 10 per cent of 377 specimens 60 to 109 centimeters).

The great majority of these fish were more or less stationary the first year after tagging, and many had shown no migration up to the beginning of the third year, which represents about the longest recapture interval. A few of the larger fish covered some distance within the North Sea, although the longest migration was that of a small fish (37 centimeters) which traveled 330 miles in 74 days.

Cod tagged in 1921–22 off Flamborough, England, were recaptured near by, most of them the same winter and the summer which followed. About 16 per cent of the cod tagged close to shore were recaptured within about a year, while about 7 per cent of the offshore tagged fish were retaken. (Graham, 1924, pp. 47–50.)

Concerning the migration of cod in northern Norway, Hjort (1926, p. 8) points out that the mature fish undertake extensive migrations, "thousands of kilometers," during the course of a year. He found that there was a yearly migration from the Barentz Sea southward along the Norwegian coast and a return migration back to the Barentz Sea. (Ibid., p. 9.)

Around the Faroe Islands 4,093 cod were marked from 1909 to 1913. (Strubberg, 1916, p. 3.) Most of these were from 30 to 90 centimeters (12 to 36 inches) long, the majority being below 60 centimeters. From 4,086 of these marked fish, 1,658, or 40.5 per cent, were subsequently recaptured. (Ibid., p. 78.) The time interval for the 1,562 recaptures made from the experiments of 1909–1912 was as follows: 1,082 fish within 6 months, 334 fish in 7 to 12 months, 113 fish in 13 to 18 months, 26 fish in 19 to 24 months, and 7 fish over 24 months. As a result of all these cod-marking experiments around the Faroes, the percentage of recaptures from various lots of fish ranged from 14.9 to 62.3, with a mean of 40.6 for all the fish. This being so, Strubberg believes that the values found indicate that from one-seventh to one-half (according to locality) "the growing stock of 35–50 centimeter fish—the 2-year olds—are taken annually." (Ibid., p. 79.) The 2 and the 3 year old fish were virtually stationary, often being recaptured in the same place after more than 21 months, and a few were even taken later. The older fish were more migratory, although some of these, too, were stationary. None of the cod left the Faroes, and only a few moved as far as 60 miles. "* * * it would seem that the bank (Faroe Bank) has its own stock of cod, * * * the stock, moreover, being capable of itself replenishing the loss occasioned by a fishery of considerable intensity." (Ibid., p. 84.)

Around Iceland cod tagging was done in 1904–5 (Schmidt, 1907) and in 1908–9 (Saemundsson, 1913). During the earlier experiment, in 1904–5, the tagging occurred on the north and east coasts where a total of 491 cod was marked. Most of them were 40 to 60 centimeters (16 to 24 inches) long and, according to Schmidt (1907, p. 13), were not adult fish. Out of one lot of 297 cod tagged off the east coast in 1904, in a locality where a relatively large amount of fishing was done, 26, or 8.7 per cent, were subsequently recaptured, while of 194 tagged about the same time but in a locality where very little commercial fishing was done only 3, or 1.6 per cent, were retaken. Schmidt (1907, p. 15) concludes, and no doubt correctly, that the greater amount of fishing which obtained in the one locality was responsible for the greater return of tags. This also points to the localization of the fish, for 20 were taken the same season, 8 the next, and 1 later, and none migrated farther than a few miles. Even the 8 recaptures made the second season were taken near the tagging grounds, where they spent the winter and spring in water around 0° C., although they could have gone to the south coast where it was warmer. (Ibid., p. 17.)

Cod marking the summer of 1905 was done on the north coast of Iceland. Of the 391 fish tagged, most of which were immature, 2 were recaptured in August and September, 1905, and 6 from May to October, 1906, all of them on the north and northwest coasts. (Ibid., p. 19.) Subsequently 7 more of these fish were reported (Saemundsson, 1913, p. 8); 5 on the north and west coasts and 2 on the west and southwest coasts. These last two recaptures taken the summer of 1907 are of particular importance, for the fish had reached maturity in the two years since tagging and had migrated toward the spawning grounds off southern Iceland. Another lot of 26 cod was tagged on the east coast during the summer of 1905, and of these 2 were recaptured near by the same summer. Cod tagging was continued during the summers of 1908 and 1909, when 27 and 200 immature fish, respectively, were marked. The few fish of 1908 were tagged on the north coast and the one recapture, made 13 months later, was from near the tagging locality. During the summer of 1909 tagging was done for the first time on the southwest coast. Twenty-one of the fish were recaught within 3 months, and 9 of them within 10 to 14 months. All but 1 of the 25 specimens from which good locality records were obtained were taken in Faxa Bay near where they were tagged.

As a result of the cod experiments made off Iceland since 1904, it has been found that the fry which are carried by currents from the spawning grounds on the south and west coasts to the north and east coasts stay there for three or four years, but seek the warmer water off the southern coast of Iceland when maturity approaches. (Saemundsson, 1913, p. 34.) Schmidt (1907, p. 23) believes that the reason these north and east coast Icelandic cod make a spawning migration to the south and west coasts is that they become more sensitive to the cold water as they near maturity. Saemundsson (1913, p. 34) states that Iceland has its own stock of cod because no recaptures of tagged fish were made outside of there.

The great drop in the number of tagged cod that has been reported recaptured after more than a year, particularly in those experiments recorded by Boreley (1909) and Strubberg (1916, 1922), was due in part to the intensity of the local fishing which removed so many of the marked fish within the first year and in part to the large number of fish that lost their tags. Graham (1929b, p. 23) points out that the percentage of marked fish recaptured in a year has frequently been used as a minimum value in calculating the percentage of the stock taken by the fishermen, and that his tank experiments make it apparent that this value should be increased to account for the loss of tags. As we have found in our cod-tagging experiments off the New England coast (1923–1929) that the loss of tags the first year is very great, it is evident that the percentage of tags returned is not a good criterion in estimating at what rate the fishery depletes a stock of fish, other than that the percentage of tags returned must be considerably less than the actual percentage of the stock of fish caught. Most of the cod tagged in the European experiments were less than 60 centimeters long, hence it would not seem that death due to old age was an important factor in the small number of returns subsequent to the first year after marking.

The results of all these cod-tagging experiments agree in one important respect, namely, that most of the fish remain more or less stationary for long periods and that each region—the North Sea, coast of Norway, the Faroes, and Iceland—has its own stock of fish. In a few cases a migration was indicated, as along the coast of Norway and from the north to the south coast of Iceland.

Certainly the thousands of cod that have been tagged in European waters during the past 25 years, and the great percentage of recaptures returned by the intensive fishing which prevailed in all the tagging areas, would have revealed an intermigration if it had occurred between such localities as the North Sea, the Faroes, and Iceland. Very likely deep water prevents an intermingling of these various stocks of fish, although Jensen (1905, p. 11) found cod otoliths (*Gadus callarias*) at the bottom of the polar deep off the Faroes and comments on the fact that both Hjort and Schmidt report cod in the upper 60 fathoms in that region, taken with hook and line and with drift nets, over depths of 350 to 1,000 fathoms. Furthermore, the very fact that cod in the North Sea and elsewhere did not migrate soon after being tagged, but remained in the same general locality for several years, indicates that, taken as a whole, they are not a roving fish even though upon occasion some schools of fish may make extensive migrations.

The causes of migrations such as those of the Icelandic cod are not so evident, although it has been suggested that a low temperature and the urge to spawn caused these fish to seek the southern coast of the island. The fact that cod up to about 4 years of age remain off northern Iceland in the 0° C. water of winter and spring when they could so easily migrate into warmer water is of interest. There are instances in American waters, too, where cod are caught in very cold water as, for example, in the Gulf of St. Lawrence and on the Grand Banks where the bottom temperature is frequently below 0° C.

REVIEW OF COD TAGGING OFF THE NEW ENGLAND COAST

The only previous cod-tagging experiment on the American coast was carried out during the years 1897–1901 by the United States Fish Commission. (Smith, 1902.) These cod were caught primarily for the purpose of securing spawn and were retained in a large cistern at Woods Hole, Mass., until they were spent. All were caught on Nantucket Shoals during late October and November with hook and line by the Fish Commission schooner *Grampus* and by commercial fishing vessels. The spent fish were weighed, measured, tagged, placed in live cars, and then towed out into Vineyard Sound or Buzzards Bay, where they were liberated.

The tags used in this experiment were made from sheet copper, cut in pieces five-sixteenths to three-fourths inch long and one-fourth inch wide, with a hole punched on one end. A fine copper wire was used to attach the tag to the fish. Different points of attachment were tried, among them the bases of the three dorsal fins, the two anal fins, and the upper and lower caudal lobes. Smith concluded, however (ibid., p. 194), that the upper part of the caudal fin near the base was the best. Smith found that some tags were lost by gradually tearing from the fin, but stated that the available evidence failed to show that many tags could have been lost in this manner. However, no tagged fish were taken by the tagging vessel *Grampus*, and therefore there was no opportunity in the field to check the number of fish having scars caused by the tag tearing loose. The fine wire used by Smith would leave scarcely any wound or scar after it had been lost by the fish, and no fisherman would have recognized a fish as having lost its tag. Without our observations in the field, we, like Smith, would have greatly underestimated the losses of tags. Then, too, the tags used by Smith were in two pieces—sheet metal and wire—therefore movable and more liable to loss than the rigid 1-piece tags used in the present investigation.

TABLE 1.—*Numbers of cod tagged and recaptured as a result of the marking experiments made off Woods Hole from 1897 to 1901*

December–January–February	Fish tagged	Subsequently recaptured	Percentage recaptured
1897–98	562	35	6.2
1898–99	593	30	5.0
1899–1900	1,421	22	1.5
1900–1901	1,443	53	3.7
Total	4,019	140	3.5

TABLE 2.—*Summary of recaptures, by localities and months, of tagged fish released in the vicinity of Buzzards Bay during 1897–1901*

Month released	Locality of recapture	Recaptured												
		During first year											During second year	
		Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Nov.	Dec.	May
December	Nantucket Shoals					2	3	1	2	1		1		
January	do				1	14	9	6	4	1	1			
February	do				2	1	3			2				
December	Marthas Vineyard and No Mans Land.		2											
January	do		2				3						1	
February														
December	Rhode Island	2				3	1							
January	do		1	2	5	7	9	2				1		
February	do				1	2	3	1						1
December	Long Island		4	3	1									
January	do		4	5	1	4	1							
February	do					2								
December	New Jersey		2		1	2								
January	do			1	1	1								
February														
December	Elsewhere				1									
January	do								1					
February														

In discussing the dispersal and movements of the tagged cod Smith (pp. 199-200) states that:

> Shortly or immediately after their release, there was a well-marked southerly and westerly movement to the shores of New York and New Jersey, where they remained during the first four months of the year.
>
> The fish showed but a slight tendency to go to the eastward of Cape Cod or of Nantucket Shoals. A few were taken between May and August, southeast of Chatham, but only one was reported from South Channel and one from Georges * * *.
>
> None of the tagged fish has been taken north of Cape Cod. If the schools with which the tagged fish mingled on Nantucket Shoals and elsewhere behaved as did the tagged fish, it is evident that the cod inhabiting the grounds off southern New England, New York, and New Jersey belong to a distinct body, and are not simply a part of the vast shoals found in Massachusetts Bay and on the coast of Maine.
>
> The conclusion seems legitimate that the cod which resort to the shores of New York and New Jersey in winter do not represent an independent body of fish which have come from some offshore grounds at this season, but are a part of the great schools of shore cod which also frequent the southern New England coast.
>
> Some fish released side by side became widely separated in a short time, while other lots appeared to keep together for several months. Some were moved by individual instincts, others seemed to act en masse. * * *

The tagged cod were found along the Rhode Island shores from November to June and on Nantucket Shoals from April to September. In October and November only 1 tagged cod was reported from Nantucket Shoals despite the fact that the *Grampus* fishing there at that time caught 4,000 to 6,000 cod annually, and commercial fishermen were active there during the same period each of the years from 1897 to 1901. Because of this Smith suggested that the fish which frequent Nantucket Shoals in the spring and summer, when 41 tagged cod had been caught there, represented a different body than was present in the fall when only 1 tagged cod had been caught.

Bigelow and Welsh (1924, p. 419) concur with Smith's views on the movements of the cod in the southern part of its range, for during the period 1901 to 1922 no further experiments were carried on and no information had come to light that could alter the preceding conclusions.

DEFINITION OF TERMS USED

At this time it is desirable to define the terms used in this book which deal with the movements of the fish, for these terms often are broadly interpreted and might easily lead to confusion.

A migration applies to a movement of a body of fish from one region to another and back again.

The term emigration is used to designate a movement of a body of fish away from a region, presumably not to return.

Similarly, immigration is a movement into a region, presumably to remain.

Individuals which appear to leave the main contingents are referred to as strays or stragglers.

The word "shoals" standing alone always refers to Nantucket Shoals.

METHODS

The study of migrations was carried on chiefly by tagging experiments. It was found that by concentrating on restricted parts of the larger fishing grounds, such as Nantucket Shoals, instead of continually searching for new places to fish, there

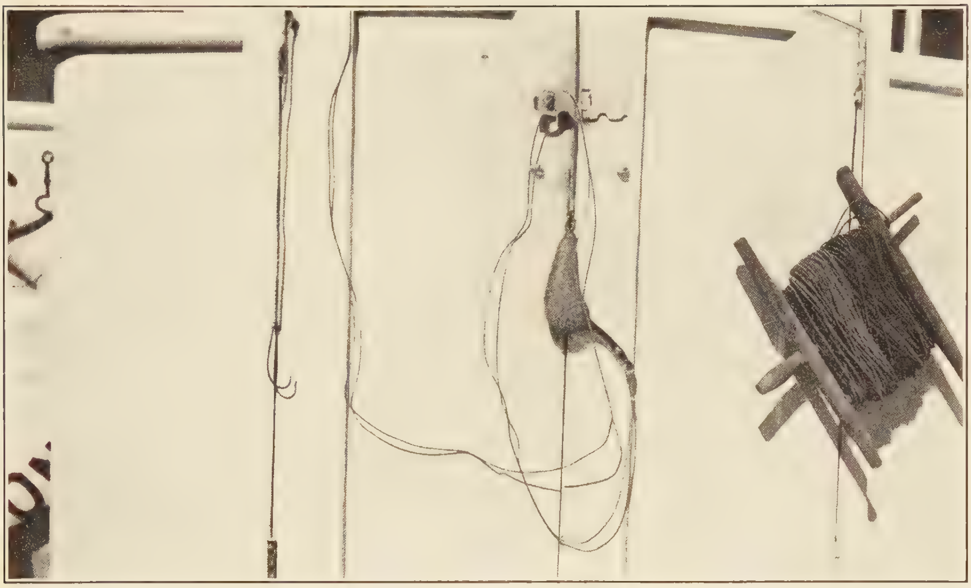

Figure 1.—Type of hand-line gear used by New England fishermen, showing reel with 50 fathoms of line, lead weighing 3¾ pounds, 6-foot leader, and hook

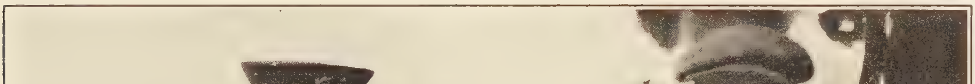

Figure 2.—Cod lying on measuring board, about to be tagged

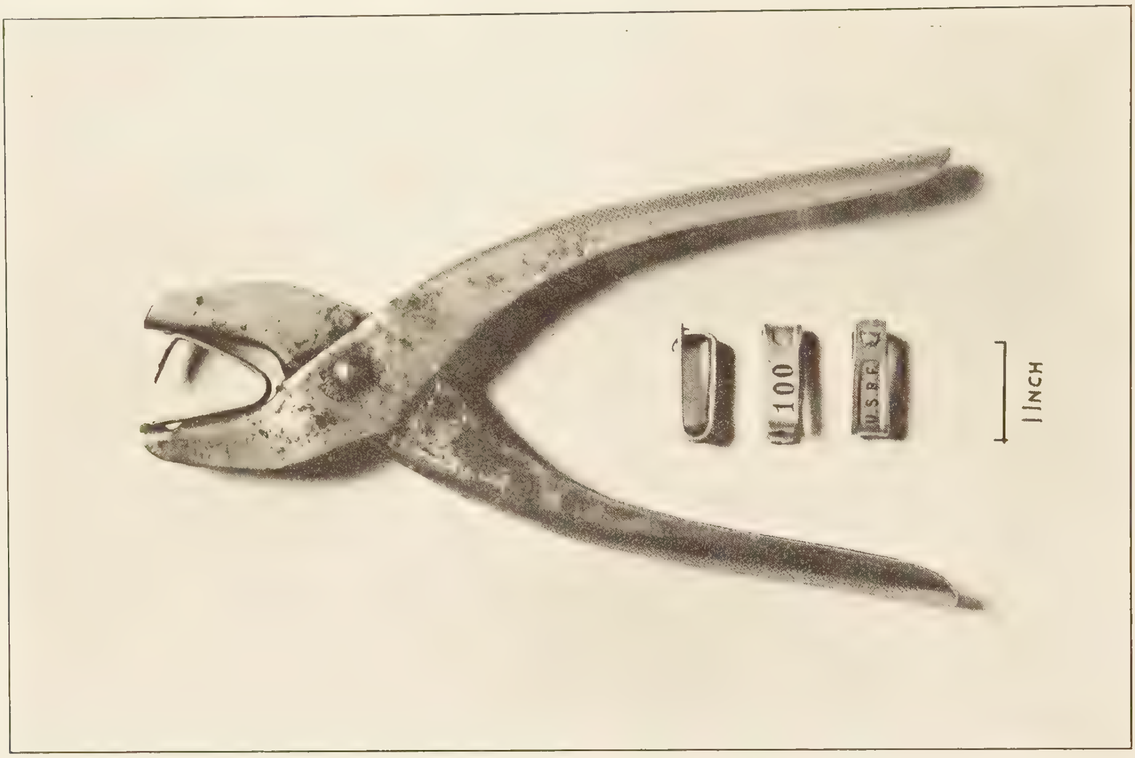

Figure 3.—Type of tag, and clamping tongs for attachment, used in the New England cod marking experiments

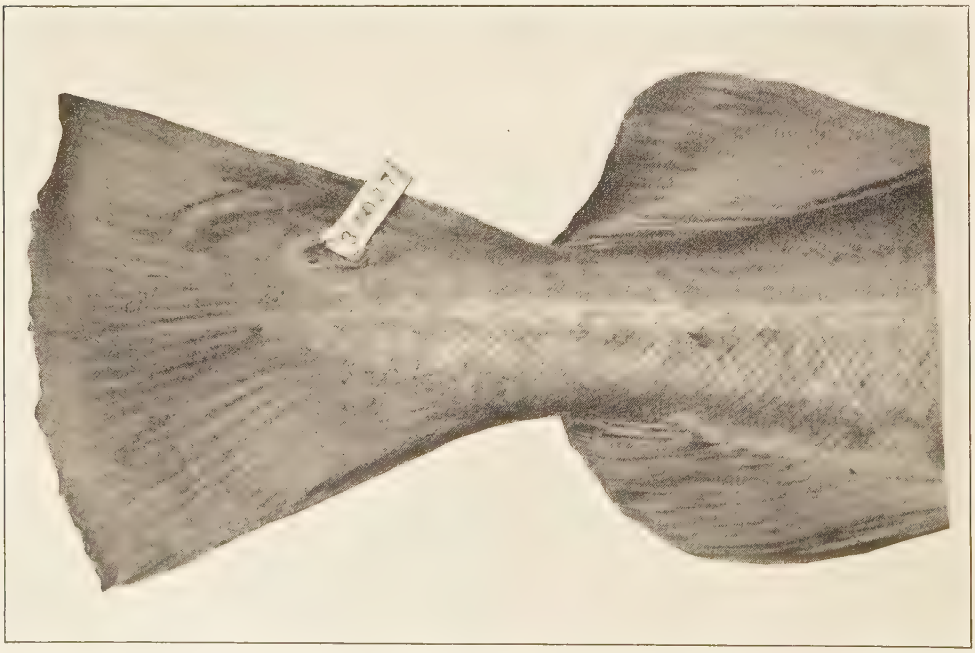

Figure 4.—A cod with tag attached to the tail. This fish had carried its tag over one year

was a better chance to get a true picture of seasonal fluctuations in abundance and size, which would reflect any migrations that might take place.

To insure that only fish in good condition were tagged, most of them were caught with ordinary hand lines of a kind in general use by commercial fishermen along the New England coast (fig. 1), for in this way only a small percentage were lost through injury. The use of the otter trawl was prohibited not only by the uneven and rocky bottoms fished upon but because a large proportion of net-caught fish are crushed or drowned by the time they are hauled out of the water. A few hundred of the fish tagged were caught on long lines, or trawl lines.

The most productive fishing was found in depths of less than 50 fathoms. Greater depths were generally avoided, for the fish taken there often are "poke blown"; that is, the æsophagus forced into the mouth due to the sudden change of pressure. Some idea of the losses may be had from the following: In less than 25 fathoms 37,929 cod were caught, of which 8.1 per cent were not suitable for tagging; between 25 and 40 fathoms, 2,730 were caught with an 8 per cent loss; and above 40 fathoms, 2,089 were caught with a loss of 17 per cent.

Frozen herring (Clupea) was used for bait almost exclusively up to 1925, but after then squid and other baits were used in addition. The herring proved to be the best all-around bait off the New England coast, but off New York and New Jersey conchs (Lunatia), surf clams (Mactra), and soft clams (Mya) were found to be much the best.

Immediately after its capture the fish was laid on a measuring board, its length recorded, a tag clamped to the tail (see fig. 2), a few scales scraped from the side, and then returned to the water. These operations usually required from 10 to 15 seconds for each fish. Beginning in October, 1927, certain fish were tagged on the head, chiefly those measuring less than 30 inches in length.

The desideration has always been, from the time of Fulton's first experiments (1890, p. 354) in marking cod up to those of Graham (1929c), that the type of tag should be one that would remain on the fish for a reasonably long while, that would cause no injury, and that would be sufficiently conspicuous to the fishermen. The tag adopted for use in the present cod investigation had been used successfully by Dr. Charles H. Gilbert in marking Pacific salmon and is similar to the type commonly used for ear-marking cattle but smaller, the length being 2¼ inches when the tag is extended. These tags (fig. 3) were easily attached to the tail of the fish by means of a clamp. A tag in place is shown in Figure 4.

It was necessary that the metal used for the tags withstand the chemical action by sea water for a long period and, after experimentation with various sorts, eliminating silver as too costly, monel metal was finally adopted as the most satisfactory. Results obtained from this experimentation are given in Table 3.

TABLE 3.—*The metals used and the number of tags returned to date for each as a result of the tagging on Nantucket Shoals during 1923*

Metal	Tags used	Tags returned	Percentage
Silver	1,000	47	4.70
Aluminum	2,623	102	3.90
Copper	700	35	5.00
Silver-plated copper	300	14	4.66
Monel	5,621	134	2.38

The small percentage of returns for the monel tags is not considered significant because the numbers of tags used for the various metals are not comparable. The metals other than monel were used in April, May, and June, and many of these tagged fish were recaptured during the summer and fall by the *Halcyon*, whereas the fish tagged later in the year with monel tags did not have this same chance of recapture. In 1924, of 4,387 fish tagged with monel tags on Nantucket Shoals, 124 or 2.83 per cent, were subsequently recaptured.

Scale samples were obtained from all the cod caught beginning with 1924. The scales were pressed on the pages of small blank books opposite a number corresponding to that of the tagged fish, and in this way they could be easily referred to at any time. The length of the fish and any other necessary data were kept in suitable record books.

Having established a method of marking the fish and recording the data, it was also necessary to advertise the tagging project among the fishermen and fish dealers. Cooperation naturally resulted, and much credit is due the fishermen for the many tag records which they have sent in. Without these our data would be wholly inadequate to justify sound conclusions regarding migrations.

TABULATION OF THE FISH TAGGED

A summary is given in Tables 4 and 5 of all the cod caught to the southward of Cape Cod and tagged on the present investigations. Not included with these fish are 1,859 cod marked and released directly from the dock of the United States Bureau of Fisheries biological station at Woods Hole, Mass., during each January of the years from 1926 to 1928. Besides these cod tagged between southern New England and New Jersey about 16,000 were tagged to the north and east of Cape Cod.

TABLE 4.—*Summary of all the cod tagged by the "Halcyon" and "Albatross II" off southern Massachusetts and to the westward from 1923 to 1929* [1]

Dates when each cruise began and ended	Locality	Fishing days	Fishing time	Cod tagged [2]
		Number	*Hours*	*Number*
1923				
Apr. 19–May 4	Nantucket Shoals	5	34	244
	No Mans Land	5	32	92
May 23–28	Nantucket Shoals	5	48	424
June 22–28	do	6	46	1, 144
Aug. 16–23	do	5	42	1, 795
Sept. 5–11	do	7	58	1, 354
Oct. 3–8	do	5	41	1, 556
Oct. 14–17	do	4	30	996
Total		42	331	7, 605
1924				
July 13–17	Nantucket Shoals	5	47	1, 254
Sept. 6–12	do	5	34½	964
Oct. 16–22	do	4	29	460
Oct. 25–28	do	4	35	427
Total		18	145½	3, 105
1925				
May 5–8	Nautucket Shoals	4	35	854
June 7–12	do	4	33½	673
Aug. 20–25	do	5	31	1, 158
Oct. 1–6	do	4	28	1, 048
Oct. 24–28	do	2	10	277
	No Mans Land	1	6	33
Total		20	143½	4, 043
1926				
Sept. 5–11	Nantucket Shoals	6	49	1, 604
	South Channel	1	5	2
Total		7	54	1, 606
1927				
May 4–7	Nantucket Shoals	3	16½	1, 083
	Chatham grounds	2	15	259
June 17–25	Nantucket Shoals	6	38	1, 497
	Chatham grounds	2	14	180
Aug. 31–Sept. 3	Nantucket Shoals	4	29½	1, 264
	Chatham grounds	1	4½	36
Oct. 14–17	Nantucket Shoals	4	27	1, 176
Nov. 14–21	Cholera Bank, N. Y.	6	33	166
Total		28	177½	5, 661
1928				
Feb. 18–27	Southern New Jersey.	7	25½	4
Mar. 23–Apr. 13 [3]	do	--------	--------	133
July 13–21	Nantucket Shoals	5	34¾	693
	Chatham grounds	2	5	19
Oct. 24–29	Nantucket Shoals	6	35½	280
	Chatham grounds	1	2	7
Nov. 8–24	Cholera Bank, N. Y.	10	56	134
Dec. 12–31 [3]	Southern New Jersey.	--------	--------	279
Total		--------	--------	1, 549
1929				
Jan. 1–Apr. 8 [3]	Southern New Jersey.	--------	--------	468
June 10–14	Nantucket Shoals	4	32¾	659
	Chatham grounds	1	1½	6
	South Channel	1	4½	37
Total		--------	--------	1, 170

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[1] A list of all the recaptures that were reported is given on pp. 120 to 131.

[2] The total catch of cod was about 10 per cent greater than the number that were tagged.

[3] These fish were caught with long lines with small boats.

TABLE 5.—*The numbers of cod tagged each year from 1923 to 1929 off southern Massachusetts and to the westward, according to fishing grounds*

Locality	1923	1924	1925	1926	1927	1928	1929	Total
South Channel				2			37	39
Chatham grounds					475	26	6	507
Nantucket Shoals:								
Bass Rip	164							164
Pollock Rip Lightship	31		1					32
Round Shoal buoy	4, 881	1, 105	1, 932	769	2, 949	746	105	12, 487
Between Round Shoal and Rose and Crown buoys		1, 028	76	388	254	139	473	2, 358
Rose and Crown buoy	1, 328	85	553		84			2, 050
5 to 12 miles southeast of Round Shoal buoy		796	515	3				1, 314
Between Rose and Crown and Great Rip buoys		28		75	1, 173	43		1, 319
Great Rip buoy	316		926	369	403	45	81	2, 140
Davis Bank	793	63	7		157			1, 020
No Man's Land, Mass	92		33					125
Western Long Island, N. Y					166	134		300
Southern New Jersey						416	468	884
Total	7, 605	3, 105	4, 043	1, 606	5, 661	1, 549	1, 170	24, 739

SIGNIFICANCE OF A RECAPTURE RECORD

The conclusions concerning the migrations of New England cod must necessarily be based largely upon the recapture records as furnished by fishermen and as obtained by the Bureau of Fisheries vessels *Halcyon* and *Albatross II*. Therefore, it is important to consider how much significance is to be attached to each record. The factors affecting the recovery of tagged cod which have an important bearing on this question may be classed as follows: (1) The death rate due to tagging and occurring soon thereafter; (2) deaths due to old age, enemies, disease, etc.; (3) the percentage of fish which lose their tags before recapture; (4) the intensity of fishing as affecting the tag returns; and (5) the percentage of recaptured fish which are not reported. The following discussion concerns chiefly those cod which were tagged on Nantucket Shoals.

The death rate due to tagging and occurring soon thereafter.—We have attempted to keep the loss of fish from this cause at a minimum by utilizing uninjured fish only. Although nearly every fish tagged appeared to be in good condition when returned to the water, nevertheless it is probable that a small number died from various causes attributable to the act of tagging. This loss may arbitrarily be set at 5 per cent.

Deaths due to old age, disease, enemies, etc.—Deaths due to old age doubtless occur. It seems that cod of 48 inches or more in length and upward of 10 years of age lack the vitality of smaller and younger fish, for they die sooner when taken from the water. Fewer of them survive the ordeal of capture and of tagging when returned to the water.[6] But the great majority of the cod caught for tagging purposes have been considerably below this size, hence might be expected to live at least five years longer before old age and consequent weakness would become an important factor in their death rate.

Little is known concerning the death rate due to the attacks of enemies other than man among adult or nearly adult cod. Sharks, including the spiny dogfish (*Squalus acanthias*) are perhaps their chief enemies. Other predaceous fishes such as the goosefish (Lophius) and the pollock (*Pollachius virens*) prey upon cod, although the latter can scarcely be considered a formidable enemy except to the very young. The cod itself is cannibalistic, although I have never known one to contain in its stomach another larger than 12 inches in length. However, it is common to see fresh wounds or healed scars on a cod's body, hence the destruction of adult cod by enemies may be greater than we now believe and must be considered a factor of some importance.

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[6] That some do survive is proven by the fact that a number of very large cod have been recaptured, some of them a year or more after tagging.

Some cod no doubt are killed by parasites and disease—their most apparent external parasite, which attaches itself to the gills, being *Lernæa branchialis* L. Cod living in less than 20 fathoms of water are most afflicted with this pest, but we also found it on cod caught in a depth of 47 fathoms on the northeast part of Georges Bank and in 40 fathoms on Browns Bank. Commonly three out of four cod from shoal water have from one to four of these bloodsucking parasites on the gills, and although many of these fish appear to be healthy it is possible that in time they become weakened and that some of them die, for as a rule the gills of thin fish are covered with this parasite. Sumner et al. (1913, p. 644) remark that they are "often so numerous as to affect the health of the fish." Cod are commonly infested with other parasites both internal and external, such as nematodes and caligids. External cancerous growths are occasionally seen, but deaths from this cause must be very small, for out of about 45,000 cod caught only 1 or 2 fish were afflicted with growths of this sort. About 1 fish in 1,000 of our catch has been extremely thin, while occasional fish, particularly large cod, may be weak and emaciated.

Considering that most of the cod which were tagged on Nantucket Shoals were neither very small nor very large, that almost all of them were sound and healthy, and that they were not unduly afflicted with parasites, the number of marked fish which died from old age, enemies other than man, parasites, and disease probably was not more than 10 to 12 per cent during the first year after tagging. The percentage would increase each year thereafter as the same stock of fish became older.

This is an arbitrary percentage, but the proportion of larger and therefore older fish, actually found among representative stocks of cod suggests that it can not be much too small or much too large.

Percentage of fish which lose their tags within the first year.—The fact that many fish have been caught showing tag marks[7] or the scar on the side where the scale sample had been taken proves that a considerable percentage of the tagged fish lose their tags while at liberty. This was to be expected, for in the North Sea experiments it was also found that some of the cod lost their tags. Concerning those marked on the operculum, Graham (1924, p. 51) writes:

> If the mark was tight the skin and flesh rotted under the button until the button almost fell out in the worst specimens I have, and no doubt did fall out in others which were, consequently, not returned. If the mark was loose the wire gradually worked the hole larger and larger. Some, however, have been returned in a perfectly healthy condition. In these the mark seemed to be just firm, neither tight nor loose, a condition hard to achieve in practice.

Graham mentions that a new tag designed to minimize weight and resistance to water was tried later but proved a failure.

The loss of the tag from its place of attachment requires a certain period of time, depending upon the exact point where it is fastened and upon the thickness of the tail. Cod recaptured one week from the time of tagging show practically no sore around the tag. One month later soreness has set in, but usually there is no evident sign that the tag will soon be lost. Three to four months later, on some fish the flesh is in good condition around the tag, on some suppuration has occurred while others already have lost their tags. About one year later the condition of the tagged fish may be classed as follows: (1) The tail may be entirely healed with the tag securely attached; (2) the tail may be healed but the tag retained by only a small piece of skin and flesh; (3) suppuration may have set in, although the tag is still secure; (4) suppuration may have set in and the tag is on the point of dropping off; and (5) a wound or scar may be left where the tag has eaten its way out of the tail.

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[7] By "tag mark" is meant the fresh wound, or healed scar, left when the tag has been lost by "eating" its way through the skin and flesh of the tail.

We have insufficient data upon which to determine what percentage of the fish fall into each of these categories a year after tagging, but by far the greater part of them belong to the fifth class, as they have lost their tags.

The loss of tags may be caused by insecure attachment in the first place, as in the case of small fish, or by becoming movable because of softened tissue about the point where it penetrates the flesh. There is perhaps some friction as the tag passes through the water, and the swimming movements of the fish itself may assist in dislodging a loosely attached tag. Sometimes barnacles, hydroids, etc., attach themselves to the tag and probably aid in its loss.

Some idea of the percentage of cod that lose their tags was obtained from the marked fish that were recaptured by the *Halcyon* and the *Albatross II*. A comparison of the number of tag-scarred fish with the number of recaptured tag-bearing cod that had been marked at least the year previous gave the following result: In 1924 out of 22 marked cod which fell in this category 15 bore tags and 7 had tag scars; in 1925 out of 12 fish, 6 had tags and 6 had tag scars; in 1926 out of 10 fish, 3 had tags and 7 had tag scars; in 1927 out of 36 cod, 8 had tags and 28 had tag scars; in 1928 out of 18 fish, 8 had tags and 10 had tag scars; in 1929 out of 7 fish, 2 had tags and 5 had tag scars. The total of our own recaptures, therefore, of cod with tags attached that had been at liberty at least from one year to the next numbered 42 and those with tag scars numbered 63.

All the foregoing fish were tagged and recaptured on Nantucket Shoals and most of them were tagged and reexamined upon recapture by the same person, so it is difficult to see how the fluctuations in the loss of tags from year to year could be due to differences in the technique of tagging that would result if more than one person were involved. While the rate of loss of tags from the tail may diminish once the healing has been accomplished, nevertheless our records show that after the fish have been at liberty as long as three and one-half years only about 1 out of 10,000 is recaptured with its tag intact.

In 1927 an attempt was made to reduce the loss of tags and so some of the fish were tagged on the lower jaw. Although it seemed impossible for the tag to become dislodged from its place of attachment, yet the percentage of returns from the fish so tagged has not shown sufficient improvement to justify the discontinuance of the tail-marking method.

Intensity of fishing as affecting the tag returns.—The intensity of fishing on the tagging grounds and in localities to which the fish migrate has a direct bearing on the proportion of the marked fish which are reported recaptured. Unfortunately, the data available are too incomplete to show what degree of correlation might exist in this respect. Mention is made in several parts of this report of the catch of cod taken on Nantucket Shoals and in other regions to which these cod migrate.

The percentage of recaptured fish which are not reported.—Although the tags of some recaptured fish are lost due to various causes, it can be said with assurance that by far the greater part of those obtained by fishermen are reported.

SUMMARY OF LOSSES

These various losses of tags and tagged fish might be estimated as follows: (1) Death rate due to tagging and occurring soon thereafter, 5 per cent; (2) deaths due to old age, disease, enemies, etc., occurring within the first year after tagging, 10 per cent; and (3) fish losing their tags during the first year, 60 per cent.

Within the first year after marking about 3 per cent of the Nantucket tagged cod have been reported recaptured and, if 2 per cent be allowed to cover those fish whose records are not received, the total recovery for this period may be set at 5 per cent. This, added to the 75 per cent loss just described, would leave approximately 20 per cent of the fish at liberty with their tags still attached at the end of one year. If this same rate of loss continued there would remain by the end of the second year only about 4 per cent of the original number of fish that were tagged.

The results have so far agreed very well with this theoretic expectation of tag returns, for out of 24,450 cod tagged to the southward of Cape Cod from 1923 to 1928 the recaptures reported up to the end of 1929 are divided according to time intervals, as follows: 630 fish were retaken within the first 12 months after marking; 160, within 13 to 24 months; 10, within 25 to 36 months; 1, within 37 to 48 months; and 1 was retaken more than 48 months later. As this experiment covered six years of tagging and an additional year during which tag records could be received, the mean period was about three and one-half years.

Compared with this temporal segregation of recaptures, the following results were reported from several of the European cod-tagging experiments:

TABLE 6.—*The numbers of cod recaptured during certain marking experiments in European waters arranged according to the duration of time they were at liberty*

Reference	Time in months		
	12	13–24	Over 24
	Number	*Number*	*Number*
Strubberg, 1916	1,416	139	7
Strubberg, 1922	315	19	3
Borley, 1909	40	2	0

If it were not that the tags dropped from the tails of so many of the fish, and if we knew how many, if any, of the cod died as a result of being tagged, the proportion of tagged fish retaken and the time element would be a most important basis for deducing the decline in numbers of a particular stock of cod, hence of the drain to which it might be subjected by the fishery. As it is, however, our returns do not afford the basis for calculations of this sort nor can the value of a tag record be designated numerically, too much depending on the locality of tagging, on the average size of the individuals making up the stock of fish, on the intensity of the local fishing, and perhaps on other factors of which we are not aware at present.

RESULTS

MIGRATIONS OF COD BETWEEN NANTUCKET SHOALS AND NORTH CAROLINA

EVIDENCE OF MIGRATIONS AS SHOWN BY THE COMMERCIAL FISHERY

It had long been known that cod appeared in the autumn on the grounds extending from Marthas Vineyard, Mass., to Delaware, and even farther south. Since most of these fish disappeared in summer, it was logical to conclude that they came from the east "somewhere off New England," but it was not until Smith's experiments (p. 6) that we had definite proof to show that cod from southern New England do actually migrate along shore to the Middle Atlantic States region and so form part, at least, of the stock of fish on these wintering grounds.

Each fall the first scattering cod to the westward of Massachusetts are caught about the middle of October and apparently are the vanguard of the winter migrants. Large bodies of cod follow soon after, for good catches are made beginning late in October or early in November and continue until the end of December. After this period a decline in the catch occurs off western Long Island and northern New Jersey, which is an indication that the fish continue to migrate westward throughout the fall, but few arrive after December. Off southern New Jersey there is usually no sudden winter decline in the catch of cod per unit of effort, but in this region the fish are scattered over a large area, not concentrated on rocky ledges as they are off the northern coast; hence local fluctuations in their abundance throughout the winter do not throw so much light on their movements.

Just what proportion of the shore waters west of Nantucket Shoals is inhabited by the cod over the winter is not well known. If they are to be found chiefly confined to sand, shell, gravel, and rock bottom, as fishing experience suggests, they are limited to the area inside the 50-fathom contour and, off Long Island and New Jersey, within about 50 miles of the shore. Further off the water deepens rapidly and most of the bottom is soft.

As little fishing is done more than 25 miles from shore to the westward of Nantucket Shoals, it is not possible to follow the migrations of the cod in the offshore parts of their range. But the fishery has produced ample evidence that many migrating cod travel along a route that lies within about 15 miles of the coast. It is within this band that most of the winter's catch of 3,000,000 to 5,000,000 pounds, taken between Rhode Island and Delaware, is obtained.

Our recent tagging experiments have corroborated the general evidence of a cod migration which has been furnished by the commercial fishery, for each year since 1923 cod tagged on Nantucket Shoals during the summer have been recaptured between Marthas Vineyard and Delaware during the following fall, winter, and spring, and a few have been retaken as far south as Chesapeake Bay. The results of these experiments follow.

EVIDENCE OF MIGRATIONS AS SHOWN BY TAGGING EXPERIMENTS

COD TAGGED ON NANTUCKET SHOALS

Following the cod westward from Nantucket Shoals, the nearest region that supports a cod fishery is centered off Rhode Island. As shown in Table 7, many tagged Nantucket cod have been retaken in this locality.

TABLE 7.—*Recaptures of tagged Nantucket Shoals cod made within the region from Marthas Vineyard to Montauk Point*

(A) TEMPORAL SUMMARY

Year tagged	Number tagged	Recaptured during the first fall to spring after tagging									Recaptured during the second fall to spring after tagging				
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Oct.	Nov.	Feb.	Mar.	Apr.
1923 [1]	7,514		7	4	1		1	3	5	[2] 1		1	1	1	
1924	3,105	1	2		1			1				2			
1925	4,010	1	2			1	2	1			1				
1926 [3]	1,606	1		3				1							
1927	5,020		2		1	1		2	1		1	2			2
1928	973		3					1							

(B) REGIONAL SUMMARY

Locality:	Recaptures
Muskeget Channel	1
20 miles southwest of Sankaty Light	1
No Mans Land and Gay Head	11
Mouth of Narragansett Bay	9
Point Judith	5
Quonochontaug	1

Locality—continued.	Recaptures
Fishers Island	2
Gull Island	1
Block Island Sound	[4] 12
Block Island	22
Montauk Point	6

[1] There were received, in addition, the following recapture records from cod tagged in 1923: November, 1925, 2; December, 1925, 2; November, 1926, 2; December, 1926, 1; and January, 1927, 1. All except the January record were received early in 1927 from the same fisherman and, as they do not agree with the rest of the table, are excluded because of probable error in the recapture dates.

[2] This fish was recaptured about 20 miles southwest of Sankaty Light (lat. 40° 50′ N. and long. 70° 20′ W.).

[3] 1 cod was caught in August, 1927, in Muskegat Channel (lat. 41° 25′ N. and long. 70° 19′ W.).

[4] The 7 recaptures of doubtful date, excluded from the temporal summary, were taken in Block Island Sound and are included in the regional distribution.

The numbers of marked cod recaptured, by months, closely parallel the fluctuations in the commercial catch, as the best fishing in this region occurs during November, December, April, and May.

Cod do not enter Long Island Sound farther than the mouth of the Connecticut River, according to the fishermen of that region, and no recaptures of tagged fish have been made within the sound west of Gull Island and Fishers Island. Consequently, the western route must be along the southern shore of Long Island. That this is so is shown by the recapture of 26 tagged cod within the sector between Montauk Point and Fire Island Inlet. (Table 8.)

TABLE 8.—*Recaptures of tagged Nantucket Shoals cod made within the region from west of Montauk Point to Fire Island Inlet, N. Y.*

(A) TEMPORAL SUMMARY

Year tagged	Number tagged	Recaptured during the first fall to spring after tagging							Recaptured during the second fall to spring after tagging		
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Nov.	Jan.	Mar.
1923	7,514			2			1	1	1	2	1
1924	3,105	1		2				2		1	
1925	4,010		2	2	1					1	
1926	1,606					1					
1927	5,020		1	1	1		1				
1928	973		1								

(B) REGIONAL SUMMARY

Locality:	Recaptures
12 miles west of Montauk Point	1
Amagansett	7
Wainscott	2
Watermill	2

Locality—Continued.	Recaptures
Quogue	1
Westhampton	2
Fire Island	11

The paucity of these recaptures, as compared to those from regions farther east or farther west, is partly explained by the fact that there are fewer boats per mile of coast line which fish for cod within this sector than from Fire Island to Cape May, and, also, cod may be less concentrated and therefore fewer are caught.

Farther to the westward, from Fire Island to Barnegat Inlet, there is more sport fishing for cod along the shore than within any locality of equal area along our Atlantic coast. In addition, there is the usual commercial fishing with pound nets, hand lines, trawl lines, etc. Consequently, a relatively large number of tagged Nantucket cod have been recaptured there (Table 9), and useful data have been obtained from fishermen and from masters of fishing vessels.

Table 9.—*Recaptures of tagged Nantucket Shoals cod made within the region from west of Fire Island Inlet, N. Y., to Barnegat Inlet, N. J.*

(A) TEMPORAL SUMMARY

Year tagged	Number tagged	Recaptured during the first fall to spring after tagging							Recaptured during the second fall to spring after tagging					Third season
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Oct.	Nov.	Dec.	Mar.	Apr.	Nov.
1923	7,514	1	18	10	3	3	3	1	1	1	1	1		
1924	3,105		7	11			2							
1925	4,010		9	3	1		2		1	2			1	1
1926	1,606							[1] 1		1				
1927	5,020	2	21	6	3	3	3			3	2			
1928	973		5	1	1	1								

(B) REGIONAL SUMMARY

Locality:	Recaptures	Locality—Continued.	Recaptures
Jones Inlet, N. Y	9	Long Branch	2
Cholera Bank	26	Bradley Beach	6
Long Beach	6	Belmar	1
Freeport	1	Spring Lake	2
Rockaway and Ambrose Lightship	49	Manasquan	6
Coney Island	3	Bay Head	2
Sandy Hook, N. J	2	Seaside Park	1
Seabright	6	Barnegat	11
Galilee	4		

[1] This fish was caught in May in a lobster pot off Sandy Hook, N. J.

Here, again, the numbers of tagged fish recaptured agree very well with the trend of the fishery, for by far the greater part of the season's catch is taken in this region, during November and December. The sudden decline in the number of tagged fish taken in January, as compared with December, is in agreement with the big drop in the catch which takes place at that time. While this may be due in some measure to a curtailment of fishing, brought about by weather conditions, experience has shown that cod are much less abundant after the first of the year than they are just before then.

The data obtained from one fishing ground in this region, the Cholera Bank, deserves special discussion, for from them unusually complete and desirable information regarding the coming and going of the cod have been obtained. They serve, therefore, as one of our best checks on the progress of the cod between Nantucket Shoals and North Carolina.

The Cholera Bank lies about 18 miles S. 78° E. true from Sandy Hook Point in the path of cod migrating along shore. It is strategically situated opposite the apex where Long Island joins New Jersey and where cod going westward along the coast must turn southward to continue their journey. It is a relatively small ground, good fishing being limited to perhaps less than a square mile; but in contrast to the surrounding smooth bottom, parts of Cholera Bank are rocky, and it is over these rough places that most of the cod congregate.

A year-round picture of the fish life on the Cholera Bank is made possible by the considerable amount of sport fishing that is done there from late spring to early winter [8] and even throughout the winter two or three boats generally visit there.

Our ability to draw inferences as to a migration of cod to the Cholera Bank is made possible not only by the many pleasure craft which fish there but also by the local methods of fishing. Instead of fishing a locality at irregular intervals and drifting about, as commercial hand-line fishermen do, these pleasure boats are to be found on the bank every day that weather permits. Furthermore, the boats are anchored in approximately the same place, aided by buoys and land ranges. For these reasons a better knowledge of the fluctuations of the cod stock can be obtained from the reported catches for the Cholera Bank than for any other small ground, and, therefore, these catches are one of the best evidences of a cod migration.

There are good reasons for believing that in the fall migrating cod seek the Cholera Bank region as an objective, not necessarily to remain throughout the winter but at least as a stopping place. The large number of cod caught there during a winter—far more than in any other restricted locality west of Rhode Island—is in itself strong evidence for this belief. Some idea of the number of cod present there during the height of the season may be had from the catch of the *Giralda*, on which about 100 sport fishermen using rod and reel caught 1,156 cod in four hours on December 9, 1928. If it were assumed that these fall migrants spread out evenly over the territory bounded by the 30-fathom contour (within which nearly all the known good cod bottom west of longitude 70° is found), and that those which reached the Cholera Bank were cod that happened to be in line with it, then, measured by the catches made on the Cholera, the number of cod migrating south of there would be very large. But the catches of cod made off New Jersey during the winter and spring by no means suggest that any such vast number of cod are present along that part of the coast, as would be the case if the hundred thousand pounds caught each fall around the Cholera were an unselective sample.

It is particularly important that although the Cholera Bank is less than 1 square mile in area and although it is fished intensively during November and December the stock of cod there is maintained throughout this period. This can only mean that new migrants are arriving daily in large numbers, otherwise the fish would soon be "caught up." That very few migrants arrive after December is proven by the sharp reduction in January in the number of cod caught per unit of effort, for at this time there are scarcely enough fish to satisfy the few pleasure craft that venture out on favorable days.

Further information concerning the status of the cod in the Cholera Bank region has been furnished by the masters of fishing boats, particularly by Capt. William W. Stephens and Capt. Jacob Martin, of Sheepshead Bay, N. Y., who have fished for many years on the grounds off western Long Island and northern New Jersey. Their experience with the cod in this region agrees with what has already been stated, namely, that the cod strike in the end of October and are abundant locally until the end of the year, after which only scattering fish are found. Captain Martin states that during the winter of 1927–28 the first cod was taken October 8 and the first fair catch on the 24th. Good catches of cod were made the first two weeks of January, which was considered unusual for that period.

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[8] During the summer as many as 20 to 40 or more pleasure craft carrying in the aggregate a thousand or more passengers fish daily on the Cholera Bank for sea bass (*Centropristes striatus*) and other species. A lull in the fishing occurs early in October, but with the first cod the number of boats is again increased until the cod are depleted in numbers and winter storms blow.

In order to learn something of the movements of the cod after they migrate from Nantucket Shoals to western Long Island, fish were tagged on the Cholera Bank during November, 1927 and 1928. The recapture records are given in Tables 10 and 11.

TABLE 10.—*Recaptures reported from the tagging of 166 cod on the Cholera Bank, N. Y., November 14–21, 1927*

Date tagged	Chart symbol	Date recaptured	Locality
Nov. 14	*A*	Nov. 17, 1927	Off Jones Inlet, N. Y.
Do	*B*	Dec. 27, 1927	6 miles south of Jones Inlet.
Nov. 15	*C*	Feb. 17, 1928	Off Long Beach, N. Y.
Nov. 16	*D*	Nov. 21, 1927	Bradley Beach, N. J.
Do	*E*	Dec. 11, 1927	3 miles north of Ambrose Lightship, New York.
Nov. 21	*F*	Dec. 26, 1927	Easthampton, N. Y.
Nov. 17	*G*	May 15, 1928	Nantucket Shoals.
Nov. 20	--------	Jan. 15, 1929	Delaware Bay.

TABLE 11.—*Recaptures reported from the tagging of 134 cod on the Cholera Bank, N. Y., November 8–24, 1928*

Date tagged	Chart symbol	Date recaptured	Locality
Nov. 21	*H*	Jan. 19, 1929	Off Cape May, N. J.
Nov. 23	*J*	Dec. 16, 1928	Off Long Beach, N. Y.
Do	*K*	Nov. 29, 1928	3 miles north by west from Ambrose Lightship.

These results may be summed up as follows:

1. No recaptures were reported from the Cholera Bank proper, although the fishing there was very intensive for weeks after the fish were tagged. Accordingly, as this happened both in 1927 and 1928, we can conclude that the schools of cod which arrive on the bank in the fall do not remain there for long but move on to other grounds.

2. Even though the same individual cod do not tarry long on the Cholera Bank in the fall, all of them do not necessarily move far, for a number of marked fish were recaught later in the winter 10 to 20 miles away. This is illustrated by fish *A*, *B*, *C*, and *E* listed in Table 10 and by *J* and *K* in Table 11, shown in Figure 5.

3. Some of the cod which reach the Cholera Bank in the fall continue their migration southward. This is shown in Figure 5 by fish *D* and *H*.

4. The fish *F* and *G* (Table 10 and fig. 5) went eastward and are discussed on page 33.

The percentage of recaptures resulting from the cod tagged on the Cholera Bank during November, 1927 and 1928, amounted to only 4.8 and 2.2, respectively. This was smaller than what might have been expected in view of the very intensive sport fishing that was carried on there during and directly after the marking experiments. On the face of this it would seem that most of these fish moved away very soon after being tagged and, as the number tagged was small, we could expect very few of them to be reported from the many square miles of cod grounds which extend to the eastward and to the southward.

With regard to the Cholera Bank cod taken in Delaware Bay in January, 1929 (Table 10), it is very likely that this fish returned to southern New England during the spring of 1928 and migrated westward again that fall. If this be so it shows that New England cod may make more than one winter migration to the New York-North Carolina region.

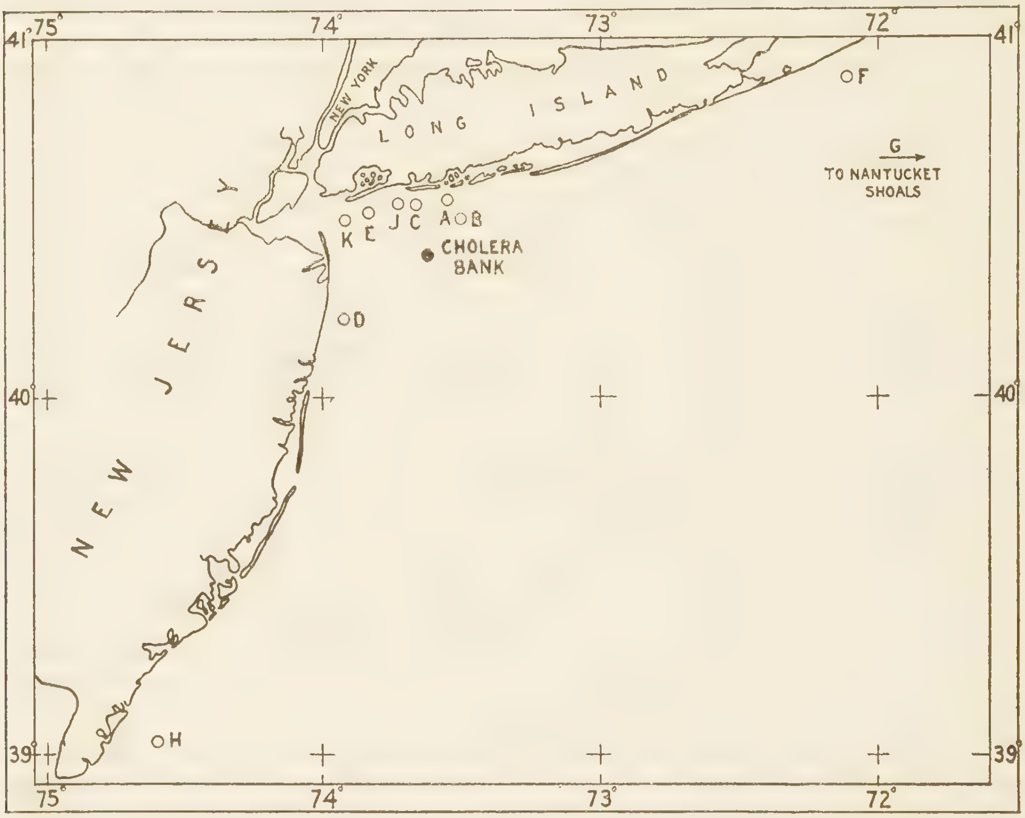

FIGURE 5.—Recaptures made during the winters of 1927–28 and 1928–29 from 300 cod tagged on the Cholera Bank during November 1927 and 1928. Each symbol represents one recapture

That southern New England cod continue their migration along the coast of New Jersey and southward is shown by the many recaptures of marked fish listed in Table 12.

TABLE 12.—*Recaptures of tagged Nantucket Shoals cod made within the region south of Barnegat Inlet, N. J.*

(A) TEMPORAL SUMMARY

Year tagged	Number tagged	Recaptured during the first fall to spring after tagging							Recaptured during the second fall to spring after tagging					Third season
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Dec.	Jan.	Feb.	Mar.	Apr.	Mar.
1923	7,514	------	3	10	5	------	1	1	2	------	1	1	------	1
1924	3,105	1	------	------	------	------	2	------	------	------	------	4	------	------
1925	4,010	------	1	3	2	3	3	------	------	------	------	------	------	------
1926	1,606	------	------	------	1	------	1	------	------	------	------	------	------	------
1927	5,020	------	4	1	2	3	7	3	4	3	3	------	1	------
1928	973	------	------	2	1	1	1	------	------	------	------	------	------	------

(B) REGIONAL SUMMARY

Locality:	Recaptures	Locality:	Recaptures
Ship Bottom, N. J.	4	Cape May	20
Beach Haven	5	Delaware Bay	2
Atlantic City	31	Cape Henlopen, Del.	2
Townsends Inlet	1	9 miles east of Indian River	2
Avalon	1	Hog Island, Va.	2
Wildwood	11	Hampton Roads	1

We can not assume that the regional distribution of recaptures along New Jersey reflects a corresponding regional variation in the abundance of fish, because fishing is much more intensive near the chief centers of population—Atlantic City and Cape May—than along the intervening stretches; that is, more returns would naturally be expected there. Without question a good part of the Nantucket cod migrate as far south as southern New Jersey and Delaware, else we would not have obtained the relatively large number of recapture records that we did. It will be noted that in this latter region (Table 12) a greater number of tagged fish were taken from January to April than from October to December—a result opposite to that which obtained for the western Long Island-northern New Jersey sector. (Table 9.) This is explained partly by the fact that the small boats of southern New Jersey fish for cod continuously throughout the winter, whereas off the northern coast and around New York City fishing is considerably curtailed after December and the great amount of sport fishing that is done there early in the year is reduced to a minimum after January 1. But even so, cod have been found to be much less plentiful off the northern coast during late winter and early spring than to the southward between Atlantic City and Delaware Bay. It would seem, therefore, that a good part of the cod which occupy grounds between Fire Island and Barnegat Inlet during early winter move farther southward and spread over the much more extensive grounds there.

Some knowledge as to whether the stock of cod off southern New Jersey are migrating fish or winter residents has been gained from the experiences of the commercial fishermen and from direct observation.

Fishermen, within their own immediate neighborhood, often can follow a body of cod from day to day, inshore, offshore, or up and down the coast by observing on which part of the 1 to 3 miles of trawl line the best catch is made. Very often a fishing boat will lay its trawls in about the same place from week to week and catch cod which are so nearly the same size as to virtually prove them to be of the same body of fish, for a much wider variation in size might be expected if they were transients. Such was our experience during the course of cod tagging off Atlantic City from March 23 to April 13, 1928. (Fig. 9.)

Along the coast of southern New Jersey cod are confined to definite areas, although they may shift ground a very short distance even over night. In cases where two trawl lines are set parallel, say about one-fourth of a mile apart, one often catches 5 to 10 times as many cod as the other. And what proved to be a good "lay" one day often fails the next, although the fish may be only a few hundred feet either side of the trawl. This shifting of the cod for very short distances shows that they must remain well schooled up at such times. Their movements probably are governed largely by their food supply. Yet in March, 1929, off Cape May, when I observed this shifting about of the cod, their stomachs contained the usual bottom forms such as crabs, shrimps, mollusks, and worms. At this time they had eaten very few sand eels, which type of food might easily have explained their moving. Although cod off New Jersey, and probably anywhere west of Rhode Island, often shift short distances from day to day, this does not argue against the belief based upon our present studies, that a school of fish may remain for weeks or months in the same general locality.

In order to learn something definite concerning the habits of the cod off southern New Jersey, fish were tagged there in March and April, 1928, and again in the winter of 1928–29. None of the former were recaptured locally, but records obtained from the latter (Table 13) are of decided interest.

TABLE 13.—*Cod tagged off Atlantic City and off Cape May, N. J., from December, 1928, to April, 1929, with a record of all recaptures reported up to October, 1929* [1]

Date	Tagging record		Recapture record	
	Locality	Number of cod	Date	Locality
Dec. 12, 1928	Off Atlantic City	12		
Dec. 15, 1928	do	50		
Dec. 19, 1928	do	31		
Dec. 22, 1928	Off Cape May	26		
Dec. 27, 1928	do	35		
Dec. 29, 1928	do	55		
Dec. 31, 1928	do	70	Feb. 20, 1929	2 miles off Wildwood, N. J.
Jan. 1, 1929	do	33	Jan. 23, 1929	2 miles southeast of North Wildwood.
Jan. 3, 1929	do	29		
Jan. 22, 1929	do	51	Jan. 27, 1929 Aug. 1, 1929	Inside of Delaware Bay. South Channel, off Massachusetts.
Feb. 11, 1929	do	49		
Feb. 13, 1929	do	52	Apr. 13, 1929	McCries Shoals, Cape May.
Feb. 16, 1929	do	51	Mar. 21, 1929	5-fathom bank, Cape May.
Feb. 18, 1929	do	7		
Mar. 11, 1929	do	26		
Mar. 13, 1929	do	18		
Mar. 18, 1929	do	40	Aug. 5, 1929	South Channel.
Mar. 19, 1929	do	9		
Mar. 21, 1929	do	22		
Mar. 27, 1929	do	11	Oct. 12, 1929	Nantucket Shoals.
Apr. 7, 1929	do	13		
Apr. 8, 1929	do	56		

[1] See p. 131 for additional records.

The few recaptures made of the cod tagged off Cape May the winter of 1928–29 prove beyond a doubt that a large part of the cod present there at that time remained in the same immediate locality without migrating. Thus we have a fish tagged December 31 and another on January 1 which were retaken in virtually the same locality 52 and 23 days later, respectively. Of the fish tagged February 13 and 16, one was retaken 33 days later about 10 miles away and another 59 days later on the same ground where it was tagged. Another fish, tagged January 22, about 10 miles off the coast, moved inshore directly afterwards, for five days later it was recaptured well inside Delaware Bay.

Further proof that these few recapture records of tagged fish are fairly representative of the body of cod as a whole off Cape May during the winter of 1928–29, is shown by an analysis of the length frequencies of various samples of cod.

For example, the length-frequency distribution (fig. 6) obtained in part from the cod tagged off Cape May (Table 13) and in part from cod caught by fishermen in Delaware Bay, may be interpreted as follows:

1. The length-frequency distribution for December and January (shown with long dashes in fig. 6) may be taken as representative of the stock of fish that was found from 2 to 10 miles off Cape May throughout those months. Although not included in the graph, the 93 cod tagged about 8 miles off Atlantic City were of about the same length distribution as these.

2. A large increase in the proportion of small fish around 21 to 23 inches long and a decrease in the large fish around 26 to 28 inches long occurred at some time

beginning in February and lasted until the end of the fishing season in April (shown by the dotted line in fig. 6). The predominance of the smaller fish was greatest in February and became less toward April, as if the larger fish gradually returned to the grounds they occupied during December and January. The cause of the sudden rise in the proportion of small fish in February may have been due to an influx of a school of cod of these sizes, to the emigration of the large fish, or to both causes. We believe that a migration of the larger cod from offshore to inshore (and inside Delaware Bay) was the chief cause, as explained in the next paragraph.

3. The solid line in Figure 6 represents an unselected sample of cod taken inside Delaware Bay on February 25, 1929. Just how representative of the bay as a whole this sample was and how long cod of these sizes were present can not be said, but, as fishermen caught good-sized cod there for some time, we have some basis for believing that the drop in the percentage of 26 to 28 inch cod offshore was caused by their migration into and around the mouth of Delaware Bay. The recapture of a tagged offshore (McCries Shoals) cod inside of Delaware Bay (Table 13) makes this supposition all the more probable.

Letters giving information about the habits of the cod off southern New Jersey were received from several fishermen, including Francis Widerstrom, Fred C. Miller, and William Hare, of Wildwood; George Williams, of Cape May; and Harry Donath, of Atlantic City. These fishermen state that the first cod appear some time between October 20 and November 15, along shore in 6 to 8 fathoms of water. In January, February, and March they are found to be more plentiful in 13 to 15 fathoms. During the last of March and in April they again are found in shoaler water, but after about April 15 virtually none are caught until the next fall, although fishing for other species of fish is done throughout the summer on the same grounds where cod are caught during the winter. That all cod do not disappear the middle of April is shown by the few stragglers that are caught as late as May.

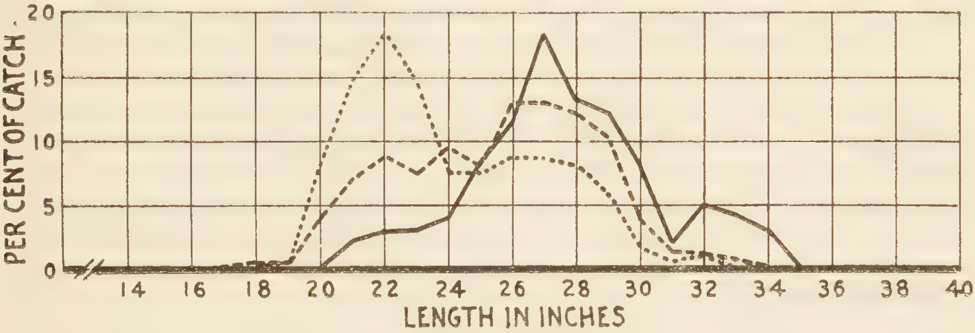

FIGURE 6.—Broken line, 298 cod caught around McCries Shoals, Cape May, in December, 1928, and January, 1929. Dotted line, 354 cod caught around McCries Shoals February 11 to April 18, 1929. Solid line, 98 cod caught in Delaware Bay February 25, 1929

On rare occasions in the past a cod has been taken far up the Delaware River, but at the present time, with the increase of commercial activities along the river, such instances are perhaps unknown. Abbott (1871, p. 116) records that—

> On the 23d or 24th of January a healthy, strong, active codfish (*Morrhua americana*) weighing nearly four pounds was taken in a drawnet. The stomach of this fish showed it had been in river water for several days. The fisherman who took this specimen considered it the first instance of the kind on record, but such is not the case. Several have been taken about Philadelphia during the past twenty years.

Several hundred barrels of cod were taken inside Delaware Bay during February, 1928. In February and March, 1929, cod were caught in the lower bay, and in February, 1930, catches were made as far up as Fortesque.[9] Various fishermen interviewed in Wildwood and Cape May asserted that they could not recall commercial catches of cod being made inside the bay prior to the winter of 1927–28, but admitted that before then they had not tried fishing for them. It may be, therefore, that schools of cod enter the bay each winter.

South of Delaware Bay the recapture of only three tagged cod has been definitely recorded, all of them in 1928, but one fishing concern reports that several marked fish were taken in the fall of 1927 but the tags had been lost. One of these southern recaptures is associated with an extraordinary catch of cod made in Chesapeake Bay during March, 1928. Harry R. Houston, commissioner of fisheries of Virginia, writes on April 5, 1928:

> For the first time in the present generation large numbers of cod have been caught inside Chesapeake Bay, the total catch being about 20,000 pounds. The fish were taken early in March in pound nets from near the capes to as far up as Buckroe Beach and ranged in size from 4 to 24 pounds. The Chesapeake Seafood Corporation, of Hampton, Va., caught in one of their pounds near Cape Henry a 24-pound cod bearing on its tail tag No. 56379.

Prior to this unusual catch 160 cod were reported caught in Chesapeake Bay during the first part of January, 1928, by the boat *Hilda Mable* while trying out a new otter trawl. Another good catch of cod was reported from the lower Chesapeake the first half of March, 1930, when as much as 1,000 pounds were taken from a single trap. The fish weighed up to 35 pounds each. It may be that cod enter Chesapeake Bay each winter, but that, like in Delaware Bay, their presence is unknown because there has been very little local fishing at that time. The last pound net is taken up in the lower bay about December 1 and the first is put down in the spring about March 1, so that the presence of cod in the Chesapeake can be made known by means of pound-net catches only during November, March, and April, and not between those months.

Two tagged Nantucket Shoals cod have been recaptured in the vicinity of Hog Island, Va., in pound nets. By a coincidence both fish were recaptured the same day, December 4, 1928, although not in the same net. Oddly enough, neither of these cod was tagged during 1928, but one dated back to September 2, at Round Shoal buoy, and the other to October 17, 1927, 3 miles northeast of Great Rip buoy, Nantucket Shoals. Even so, it is very likely that both of them left Nantucket Shoals in the same school, for they migrated a distance of about 400 miles.

The winter of 1927–28 appears to have been out of the ordinary as regards the movements of the cod in the southern part of its winter range, featuring as it did a migration into various bays along the coast. These catches were as follows:

1. Cod appeared in Sandy Hook Bay, N. J., for the first time in many years. One tagged cod released off Woods Hole was taken there.

2. Cod were caught inside Great Bay, about 10 miles north from Atlantic City. This was considered very unusual by the local fishermen.

3. Cod were caught in large numbers inside Delaware Bay for the first time, because prior to the winter of 1927–28 their presence there in commercial numbers was not known to the fishermen. One tagged Nantucket cod was taken there. Good catches were again made in the winter of 1928–29 and a cod tagged offshore from Cape May was taken inside the bay.

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[9] Fortesque, N. J., is about 24 miles from Cape May point, inside of Delaware Bay.

4. For the first time in a generation good catches of cod were made inside Chesapeake Bay, among which one tagged Nantucket cod was reported.

What brought these cod inside Sandy Hook, Great, Delaware, and Chesapeake Bays the winter of 1927–28 can not be known definitely, but it is not at all unlikely that a search for food, together with an unusually large number of fish may have played an important part. It may be significant that large numbers of sand eels were present in Delaware Bay that winter and that the stomachs of the cod caught there were full of them. But if the sand eel drew cod inside Delaware Bay then, the same can not be said for the winter 1928–29, or at least was not noted by the fishermen. During the winter of 1928–29 stomachs examined off Cape May showed that, quantitatively, crabs were the chief food of the cod. They also fed on mollusks (mostly *Lunatia heros*), worms, shrimps, and small fishes. Among the latter were small hake (Urophycis), small sculpins (Myoxocephalus), sand eels (Ammodytes), and even pipefish (Siphostoma) and seahorses (Hippocampus). The cod caught in the Chesapeake during early March, 1930, had been feeding on herring (Pomolobus).

COD TAGGED IN THE WOODS HOLE REGION

The few cod marked off No Mans Land and the recaptures made therefrom are of especial interest because they were tagged in almost the same place where Smith (1902) released all of his tagged cod. The following recapture records of our fish have been received (Table 14):

TABLE 14.—*Recapture records of cod tagged 1 to 3 miles off No Mans Land by the "Halcyon"*

Tagged		Recaptured	
Number	Date	Date	Locality
92	Apr. 21 to May 2, 1923	June 1, 1923	No data.
		Aug. 24, 1923	South Channel.
		Oct. 17, 1925	No Mans Land.
33	Oct. 28, 1925	Feb. 8, 1926	Off Block Island.
		Oct. 28, 1926	No Mans Land.

These recaptures, taken by themselves, are too few upon which to base sound conclusions regarding the migrations of the cod in this region, but, fortunately, other records were obtained from subsequent tagging experiments.

None of the 125 cod tagged off No Mans Land was taken west of Rhode Island, but this can not be considered unusual, because only 8 of Smith's cod, or about 1 out of each 500 tagged, were reported from as far as New Jersey, and nearly all of his western recaptures were made within about 70 miles of the place were the fish were released.

Further tagging in this general region consisted of 946 cod marked January 6 and 7, 1926; 422 on January 3, 1927; and 491 on January 13, 1928. Most of these fish were caught in pound nets set near the mouth of Buzzards Bay and were brought to the Bureau of Fisheries biological station at Woods Hole, where they were held in an inclosure so that their spawn could be collected and incubated in the hatchery. After being tagged, they were released directly from the dock at Woods Hole. The recapture records of these fish are given in Table 15.

TABLE 15.—*Recaptures made from 1,859 cod tagged and released directly from the dock of the United States Bureau of Fisheries biological station at Woods Hole, Mass., during January of the years 1926, 1927, and 1928*

(A) TEMPORAL SUMMARY

Localities where recaptures were made	Recaptured during same year											Recaptured second year				Recaptured third year		
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Oct.	Nov.	Dec.	Jan.	Apr.	July	Dec.	Jan.	Mar.	Apr.
Chatham grounds and South Channel						1	1											
Nantucket Shoals			2						1					1				
Marthas Vineyard and No Mans Land			1													1		
Rhode Island	6		3	3	1			2		1	1	1	1					
Long Island	5	3	2	2	1							2			1		1	
New Jersey		1	2		1													1

(B) REGIONAL DISTRIBUTION

Locality:	Recaptures
South Channel	1
Chatham grounds	1
Nantucket Shoals	4
No Mans Land and Gay Head	2
Mouth of Narragansett Bay, R. I.	4
Point Judith	1
Block Island	7
Block Island Sound	7
Montauk Point, N. Y.	6
Amagansett	5

Locality—Continued	Recaptures
Easthampton	1
Watermill	1
Westhampton	2
Jones Inlet	1
Cholera Bank	1
Sandy Hook Bay, N. J.	1
Scotland Lightship	1
Off Barnegat Bay	1
Atlantic City	1
Cape May	1

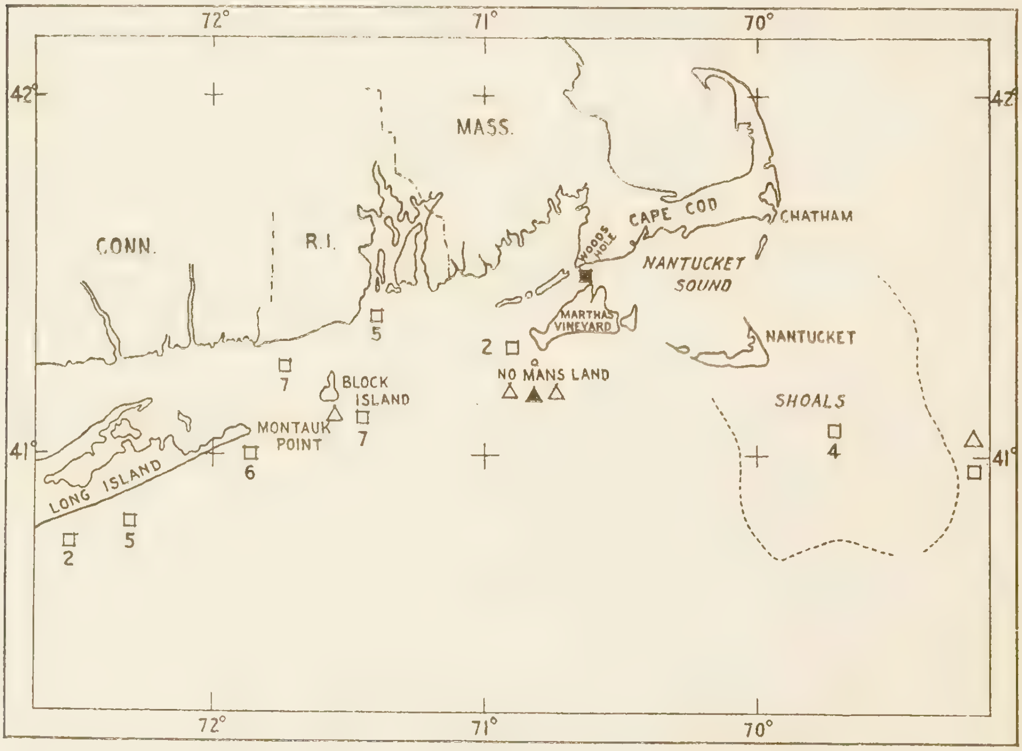

FIGURE 7.—Recaptures made east of longitude 72° 40′ W. of cod tagged off Woods Hole and off No Mans Land, Mass. The dark symbols represent tagging localities and the open symbols recapture localities. The number of recaptures is given where more than one

In general, these results closely parallel those of Smith (1902) in that many of the cod remained off Rhode Island throughout the winter (a few through the summer), some went westward early in winter, and others were recaptured to the eastward in the spring. There was no evidence that any cod went through Nantucket Sound. (Fig. 7.)

COD TAGGED ON THE CHATHAM GROUNDS

Although but few cod were tagged on the Chatham grounds, the recaptures show that the fish living there make virtually the same migrations as do those on Nantucket Shoals (Table 16):

TABLE 16.—*Recaptures of cod tagged on the Chatham grounds*

Tagged		Recaptured	
Date	Number tagged	Date	Locality
May 27, 1923	3	Sept. 17, 1923	Chatham grounds.
May 3, 1927	108	July 12, 1927	Do.
		July 25, 1927	South Channel.
		Mar. 28, 1928	Wildwood, N. J.
		May —, 1928	Ipswich Bay, Mass.
		July 10, 1928	South Channel.
		Mar. 27, 1929	Off Sandy Hook, N. J.
May 4, 1927	151	May 11, 1927	Chatham grounds.
		do	Do.
		Jan. 12, 1928	Jones Beach, Long Island, N. Y.
		Jan. 23, 1928	Cape May, N. J.
June 16, 1927	146	July 26, 1927	South Channel.
		Nov. 21, 1927	Barnegat Inlet, N. J.
		Jan. —, 1928	Cape May, N. J.
		Oct. 26, 1928	Nantucket Shoals.
June 22, 1927	34	July 26, 1927	South Channel.
		Sept. 10, 1928	Nantucket Shoals.
Sept. 2, 1927	36		
July 13–19, 1928	19		
Oct. 27, 1928	7		

Of the 475 cod tagged on the Chatham grounds in 1927, 5 were reported recaptured between western Long Island and southern New Jersey the winter of 1927–28. The movements of the two cod tagged in June, 1927, and recaptured on Nantucket Shoals in September and in October, 1928, can not be known. Possibly these fish were on their way from the Chatham grounds to the Rhode Island-North Carolina region at the time they were recaught on the shoals, or they may have made a back-and-forth migration to these wintering grounds during the winter of 1927–28 and upon their return eastward spent the summer on Nantucket Shoals instead of continuing to the Chatham grounds. The same uncertainty is attached to the fish recaptured off Sandy Hook, N. J., in March, 1929, for it may have migrated westward the fall of 1927 or 1928 or both years.

Those Chatham tagged cod which showed no migration are discussed on page 47 and the fish which went to Ipswich Bay is mentioned on page 39.

EVIDENCE THAT MANY RHODE ISLAND-NORTH CAROLINA COD COME FROM SOUTHERN MASSACHUSETTS

The small number of cod with tags (less than 2 per cent) that have been reported from west of Nantucket Shoals during any winter of record might at first sight lead one to believe that the grounds off southern Massachusetts contribute but a small part of the fish which migrate into the Rhode Island-North Carolina region. But many of the marked fish lose their tags (p. 14) and a good portion of the stock of cod on the wintering grounds survive the fishery and return eastward in the spring, thus failing to enter into the records. An illustration of the tag loss occurred the winter of 1928–29 when two fishermen engaged in tagging cod off Wildwood, N. J., noted three fish with unmistakable tag scars, but none with tags, among 653 that were caught.

But the degree of correspondence between tag returns and the total fishery from year to year is more significant than the percentage of tagged fish that are recaptured.

In order to determine whether a parallelism existed between the percentage of tagged Nantucket cod taken to the westward and the amounts of cod caught there by the fishery each winter, the recaptures for the years 1923 to 1928 are listed in Table 17.

TABLE 17.—*Recaptures of cod made the first fall to spring after tagging between Rhode Island and Virginia, divided according to the locality on Nantucket Shoals where they were marked*

Tagging locality on Nantucket Shoals	Number tagged	Recaptures made between Rhode Island and Virginia, the first fall to spring following tagging									Percentage recaptured
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total	
1923											
Round Shoal buoy to Rose and Crown buoy	6, 209	1	23	24	8	1	6	5	3	71	1. 14
Pollock Rip	32									0	
Bass Rip	164		1							1	. 61
Great Rip buoy	316		3	1						4	1. 26
Davis Bank	793		1	1	1	2			1	6	. 75
Total	7, 514	1	28	26	9	3	6	5	4	82	1. 09
1924											
Round Shoal buoy to Rose and Crown buoy	2, 246	3	7	11	1		4	1		27	1. 20
5 to 12 miles ESE. of Round Shoal buoy	796			2						2	. 25
Davis Bank	63						1			1	1. 59
Total	3, 105	3	7	13	1		5	1		30	. 97
1925											
Round Shoal buoy to Rose and Crown buoy	2, 562	1	11	6	2	3	5			28	1. 09
Great Rip buoy	926		3		2	1	2			8	. 86
5 to 12 miles ESE. of Round Shoal buoy	515			2						2	. 39
Davis Bank	7										
Total	4, 010	1	14	8	4	4	7			38	. 95
1926											
Round Shoal buoy to Rose and Crown buoy	1, 160			3	1	1	1		1	7	. 60
Great Rip buoy	444	1								1	. 23
Total	1, 604	1		3	1	1	1		1	8	. 50
1927											
Round Shoal buoy to Rose and Crown buoy	3, 287	2	26	8	6	1	6			49	1. 52
Great Rip buoy	1, 576		2		1	5	5	3		16	1. 01
Davis Bank	157					1				1	. 64
Total	5, 020	2	28	8	7	7	11	3		66	1. 31
1928											
Round Shoal buoy to Rose and Crown buoy	885		9	2	2	2		1		16	1. 81
Great Rip buoy	88			1			1			2	2. 27
Total	973		9	3	2	2	1	1		18	1. 85
Grand total	22, 226	8	86	61	24	17	31	10	5	242	1. 09

No statistics of the cod catch taken in the Rhode Island-Delaware region are available for these years. But the general opinion of the fishermen was that the catch of cod during the winters from 1923–24 to 1925–26 were average ones, that 1926–27 was slightly below normal, and that the seasons of 1927–28 and 1928–29 were among the best they had ever experienced. The percentage of tagged fish recaptured, as given in Table 17, followed very closely the trend of the fishery. As there were no marked changes in fishing intensity during this period, we may conclude that the years of heaviest migrations from southern Massachusetts are also the years when the best fishing obtains on the western and southern grounds.

Another interesting point brought out by the segregation of recaptures in Table 17 is that the western part of Nantucket Shoals contributed a larger percentage of its stock of cod to the wintering grounds than did the eastern part, if tagged fish may be taken as a criterion. Thus, from the Round Shoal, Rose and Crown, Pollock Rip and Bass Rip grounds (northern part of Nantucket Shoals on its western side), where 16,544 cod were tagged, 199 fish, or 1.2 per cent, were recaptured to the westward the first fall to spring following marking; from the Great Rip grounds (southern part of Nantucket Shoals on its western side), where 3,350 cod were tagged, 31 fish, or 0.93 per cent, were recaptured; while from Davis Bank and the grounds 5 to 12 miles east-southeast of Round Shoal buoy (toward the eastern edge of the shoals) only 12 fish, or 0.51 per cent, out of 2,331, were recaptured.

Further proof that the cod which summer off southern Massachusetts make up a large part of the winter population to the westward has been furnished by an analysis of the length-frequency distributions of the fish caught in these regions.

The size distribution of all the cod caught by the *Halcyon* and the *Albatross II* on Nantucket Shoals is shown in Figures 15 to 24. It can be seen that relatively few fish less than 23 inches long were taken on the shoals in 1923 or 1924. In line with this, very few cod less than 23 inches long were reported caught to the westward of the shoals during the winters of 1923–24 and 1924–25. The data for 1925 revealed no outstanding size group off southern Massachusetts nor to the westward. In 1926 small cod, particularly 17 to 20 inch fish, predominated on those parts of the shoals where tagging was done (fig. 19), and during the winter of 1926–27 cod 16 to 22 inches long were taken between Rhode Island and Delaware in far greater numbers than for many years past; in fact, they were the dominating size groups there that winter. The same was true of 1927, when 20 to 24 inch cod predominated on the shoals and likewise to the westward.

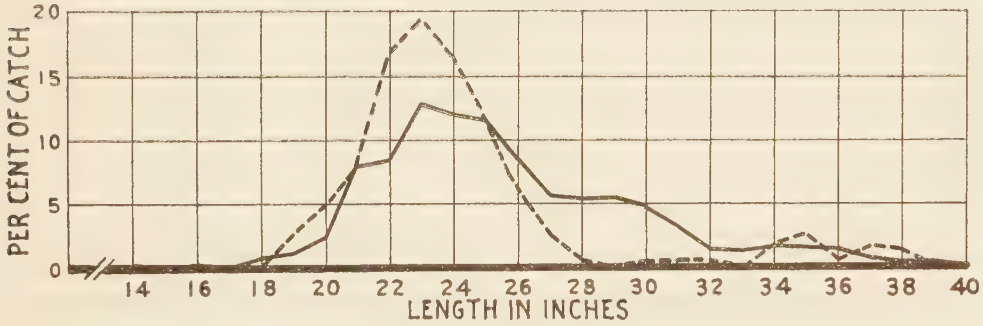

FIGURE 8.—Length-frequency distribution of 1,291 cod caught on Nantucket Shoals October 14–17 (solid line), and 185 taken on the Cholera Bank, November 14–21, 1927 (broken line)

The fall of 1927 it was possible to make a direct comparison between the lengths of the cod on the Cholera Bank in November and those of the fish present in Nantucket Shoals the preceding month. These are shown in Figure 8. It can be seen that the fish centering around 23 inches formed the dominant size group both on the shoals and on the Cholera Bank. The 29-inch Nantucket fish were evidently not present on the Cholera Bank at the time we fished there. These larger fish were caught chiefly at Great Rip buoy, and it is interesting to note that according to the recapture dates of these Great Rip 1927 fish (Table 17) they migrated westward from Nantucket Shoals later in the season than did those from the Round Shoal grounds, which might account for their absence in our Cholera Bank catches.

This, however, fails to explain the paucity of cod larger than 27 inches long off southern New Jersey in March and April, 1928. (Fig. 9.) These fish were caught on a trawl line during 10 days' fishing. Although the similarity between the two catches as they appear in the graph is not close, nevertheless the bulk of the cod present off Atlantic City at that time is best interpreted as of the same stock as had inhabited Nantucket Shoals in October, 1927, for the following reasons:

1. Nantucket tagged cod were recaptured off southern New Jersey the late winter and early spring of 1928. (Table 12.)
2. The increase of 2 inches (from 23 to 25) in the predominating lengths of Nantucket-New Jersey cod may reasonably be charged to the normal growth to be expected from October to April.
3. The great predominance of 25-inch cod off southern New Jersey was due in part to a scarcity of fish larger than 27 inches.
4. The local and temporal scarcity of large cod off Atlantic City was not representative of the coast line or of the winter as a whole, for large cod were reported from time to time off Long Island and New Jersey and even as far southward as Chesapeake Bay.

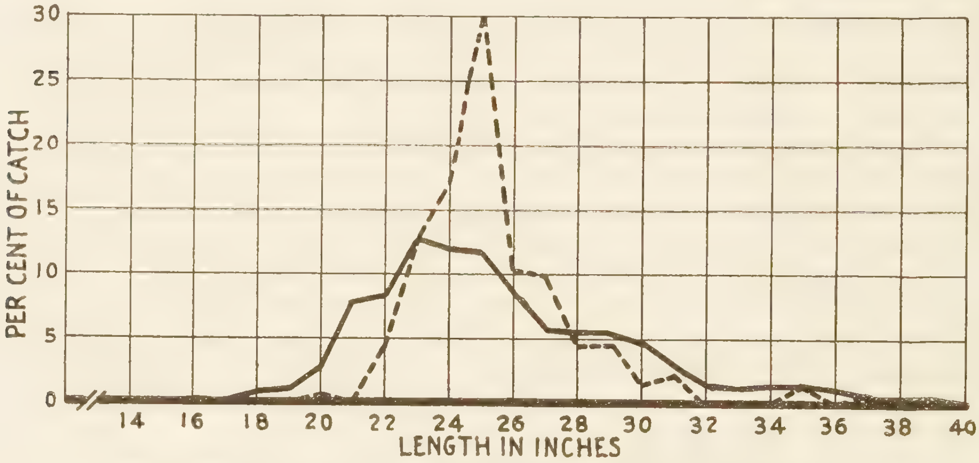

FIGURE 9.—Length-frequency distribution of 1,291 cod caught on Nantucket Shoals October 14-17, 1927 (solid line), and 134 taken off Atlantic City, N. J., March 23 to April 13, 1928 (broken line)

The next winter, 1928–29, more cod were tagged off southern New Jersey, and, as a result, it was possible to compare further the lengths of the cod which summer on Nantucket Shoals with those which winter to the westward. The lengths of these fish are shown in Figure 10. Like the previous winter, there was a 2-inch difference in size between the summer and the winter fish, very likely due to growth. As this increase of 2 inches occurred under very much the same conditions during both years, it must be considered significant in identifying the stock of cod present on the southern wintering grounds with that which summers off Nantucket.

The status of the 27-inch Cape May fish is not so clear, for they are of the same size as the Nantucket fish of the previous fall. Either they had not grown appreciably from October to March or they were so mixed with fish from other regions that their identity was lost.

According to all the foregoing data on lengths, it would appear, making due allowance for the difference in size due to growth, that the cod which populate the grounds off New York and New Jersey (and, no doubt, farther southward) in winter are chiefly from the same stock which spends the summer off southern New England.

There is no doubt that some of the fish come from other regions such as Georges Bank and Massachusetts Bay, for numbers of very large cod, such as we have seldom found on Nantucket Shoals, are taken from time to time during the winter off New York and New Jersey. But as only 5 cod out of about 16,000 tagged to the northward of Cape Cod were reported recaptured to the westward of the shoals (p. 93), it is evident that these northern grounds furnish but a small proportion of the fish which occupy the southern wintering grounds. Still further evidence is furnished by a comparison of the scales of the cod living to the northward and southward of Cape Cod (p. 110), for, considered as a whole, it has been found that the latter fish, but not the former, possess the same type of scales as do the cod found off New York and New Jersey.

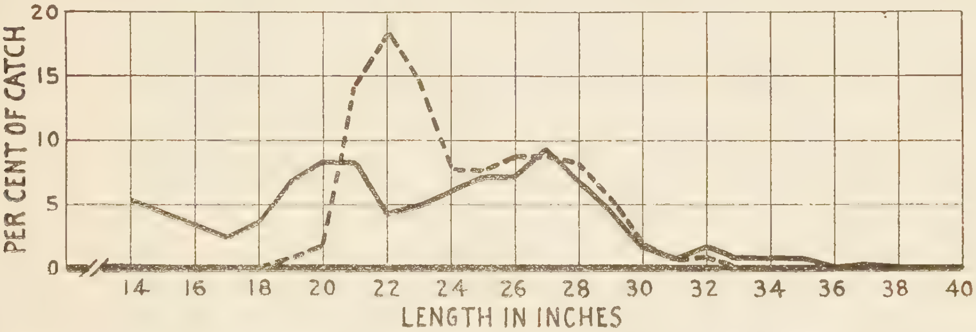

FIGURE 10.—Length-frequency distribution of 304 cod caught on Nantucket Shoals in October, 1928 (solid line), and 354 taken off Cape May, N. J., February 11 to April 18, 1929 (broken curve)

SOUTHERN LIMIT OF THE COD

Relatively few catches of cod have been reported from south of Delaware; hence we have but little knowledge of their migrations or abundance in that region. If the intensity of fishing were anywhere near as great as it was north of Delaware Bay, it is probable that rather large catches of cod would be made in the southernmost part of their wintering ground. Apparently the fish are more scattered south of New Jersey, and it does not pay to fish for them in competition with the large catches taken to the northward. Furthermore, even if cod could be caught in fair quantities off Virginia and North Carolina, it is doubtful if any of the small boats which fish in that region would make the long trip that would be necessary to reach the fishing grounds.

That cod do occur south of Delaware in more than scattering numbers has been shown by a catch made by the mackerel schooner *Relenter*, of Gloucester, which caught some 600 pounds of large cod about 8 miles south of Cape Charles, Va., on April 5, 1880 (Goode, 1884, p. 202), and by the catches made inside Chesapeake Bay in January and March, 1928, and in March, 1930 (p. 24). Other catches of record include one made by the *Clare*, which caught 8 cod off Currituck, N. C., on March 22, 1929, while dragging for croakers, and one made by an otter trawler which took 3 cod off North Carolina in February, 1929.

Along the shore between Delaware and Chesapeake Bays cod are caught each fall in pound nets, and for brief periods a small run occurs. The fall of 1928, 2 tagged

Nantucket cod were taken in nets set off Hog Island, about 22 miles northward of the Cape Charles (Va.), Lighthouse, which is located at the entrance of Chesapeake Bay. In addition to these 2 fish several others were recaptured in the same locality, but their tags were lost.

Smith (1907, p. 382) states that small numbers of cod are taken in fall, winter, and spring as far south as the latitude of Roanoke Island, N. C., while a few round Cape Hatteras, and stragglers have been observed about Ocracoke Inlet. (Goode, 1884, p. 202.) This is the most southerly record for the species. It seems that odd cod even stray into Pamlico Sound. (Smith, ibid., p. 382.)

RETURN MIGRATION OF COD TO NEW ENGLAND FROM SOUTHERN WINTERING GROUNDS

Having followed the cod to their southern wintering ground in the fall, it is logical to conclude that in the spring they return to New England waters by somewhat the same route. However, while the good catches made in the fall along the immediate coast from Rhode Island to Delaware indicate that a large part of the cod follow the shore route westward, the route taken eastward differs from this. Thus, although good catches are made close to shore off southern New Jersey in March and April and off eastern Long Island and Rhode Island in April and May, the catches off western Long Island and northern New Jersey are relatively small after January 1, with only a slight increase in the spring. This scarcity of cod in the angle, contrasted with the good catches made in the spring off southern New Jersey and around eastern Long Island, shows that the fish as they return eastward cut across the New York bight at the apex of this reentrant angle of the coast line, thus shortening their route.

In the most southerly cod region, around Cape Hatteras, the latest records of catch are for the first week of April. Farther north, near the mouth of Chesapeake Bay (off Hog Island), cod are taken in pound nets until about April 15; and along the coast from Delaware to Nantucket Shoals the following are the latest dates when tagged cod have been recaptured and which coincide closely with the end of the commercial fishery: South of Barnegat Inlet, April 22; Barnegat Inlet to Fire Island, May 7; east of Fire Island to Montauk Point, May 2; east of Montauk Point to Marthas Vineyard, May 24.

Cod are seldom caught west of Rhode Island during the summer in spite of the fact that there is considerable sport and commercial fishing there at that time. The latest record for Cape May, N. J., is May 23, when 2 cod were taken there by a flounder dragger. Off northern New Jersey, Capt. Jacob Martin of Sheepshead Bay, N. Y., records the capture of a number of cod during July and August and very exceptional catches of 70 and 35 fish taken on a ground known as the "Farms" on September 22, 1921, and September 22, 1926, respectively. Very likely these fish were "left overs" from the previous winter.

Apparently very few cod move out to the deeper waters off the Long Island and New Jersey coasts to spend the summer, for, although the bottom temperature of 43° to 53° F. at 10 to 50 fathoms (p. 74) is as cool or cooler than the maximum summer temperatures of Nantucket Shoals, and an abundant food supply of crustaceans is present (Linton, 1901, p. 471), tile fishermen who operate along the continental shelf catch only straggling cod in the summer.

That a few cod summer off Rhode Island is proven by the occasional catches that are made there at that time, but these have never been large enough to suggest that a good-sized body of fish are present.

Corroborating the evidence furnished by the fishery that nearly all the cod which winter west of Nantucket Shoals leave there by spring, we have definite proof from tagged fish that a great part of these cod return to the grounds off southern Massachusetts to spend the summer. (Fig. 11.) Thus many of the cod tagged off No Mans Land and Woods Hole by Smith (1902) and on the present investigation (p. 26) summered on Nantucket Shoals, and 2 of the 7 cod that were recaptured from the 166 tagged on the Cholera Bank in November, 1927, had swum eastward, 1 to be recaptured December 26, 1927, off Easthampton, N. Y. (about 75 miles eastward from the Cholera Bank), and the other on May 15, 1928, on Nantucket Shoals. In addition, the 1 recapture to be reported from the 133 cod tagged off Atlantic City in March and April, 1928, was taken on Nantucket Shoals July 22,′1928, and 3 of the fish tagged off Cape May the winter of 1928–29 were recaptured in the Nantucket-South Channel region the following August and October. (Table 13.)

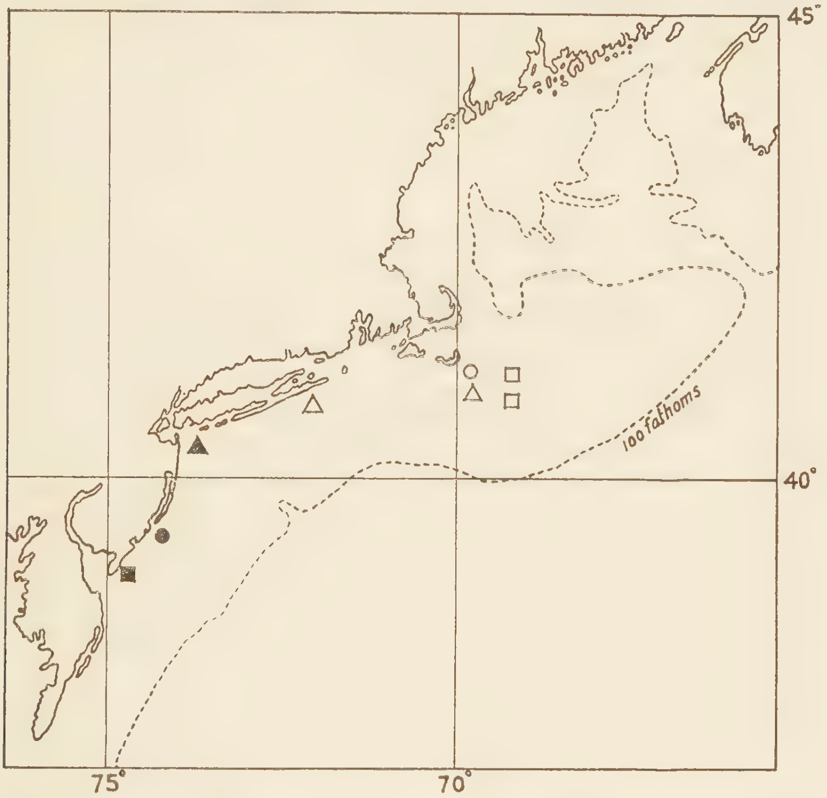

FIGURE 11.—Recaptures made off eastern Long Island and in the Nantucket Shoals region of cod tagged during the winter off Long Island (black triangle), Atlantic City (black disk), and Cape May (black square)

These 6 recaptured fish which showed a migration from west to east out of a total of 1,183 tagged to the westward of Rhode Island since 1927 represent a return of only 0.51 per cent, where the returns from the east to west migration have averaged 1.09 per cent out of 22,228 tagged on Nantucket Shoals up to the end of 1928. But if thousands of cod had been tagged west of Rhode Island as they were to the eastward on Nantucket Shoals, and if we had on the shoals the great intensity of sport and commercial fishing which is carried on in the New York-New Jersey region, it is very likely that a larger percentage of the fish tagged on the wintering grounds would have been taken to the eastward the following spring and summer.

It is probable that a small part of the cod are returning to New England waters throughout the winter, not necessarily waiting until the spring. This is indicated by the November tagged Cholera Bank cod which was recaptured off Easthampton in December, already mentioned. Perhaps this straggling eastward throughout the winter, together with the depletion in the number of fish due to the fishery, etc., may explain why the fishing during the return migration in the spring is notably poorer, with the exception of off Rhode Island, than during the westward migration in the fall.

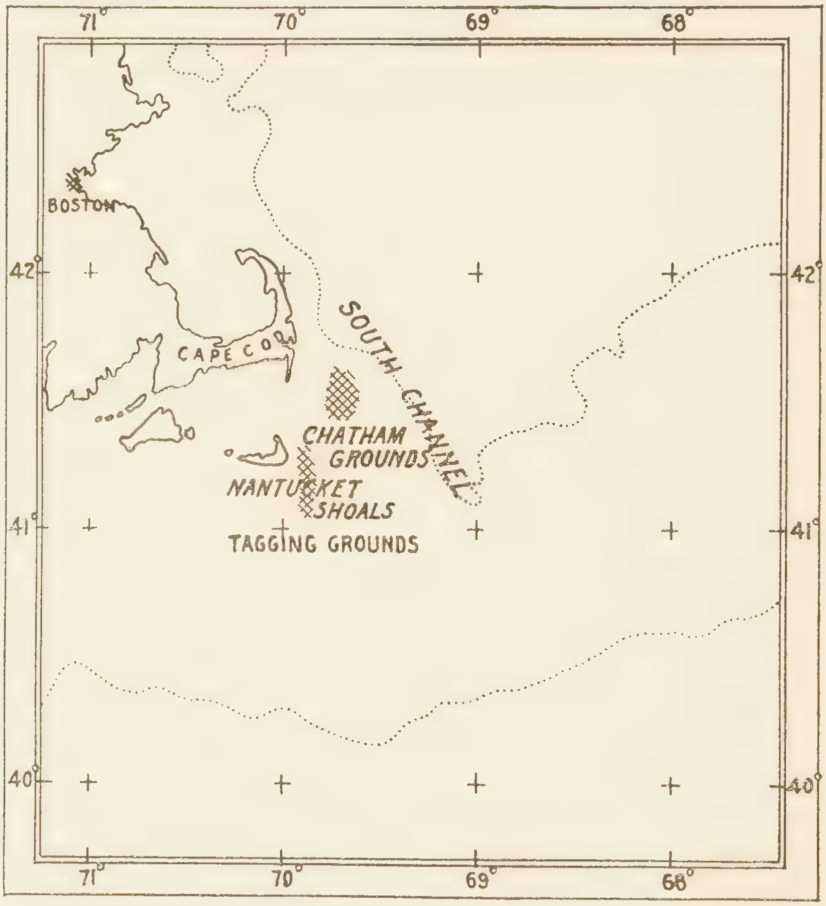

FIGURE 12.—The location of the Chatham-South Channel region with respect to the tagging grounds on Nantucket Shoals

SUMMARY

Each year, beginning about October 15, some of the cod migrate from the grounds off southern Massachusetts into the region extending from Rhode Island to Delaware and even as far south as Cape Hatteras, N. C. This migration continues until December, after which only straggling fish go westward. Cod from north and east of Cape Cod also join in the fall migration to the westward of Nantucket Shoals, but they appear to form a minority of the stock of fish on the wintering grounds. The total number of cod which enter the Rhode Island-North Carolina region each winter must be large, for the catch there usually ranges between three and five million pounds. After the cod leave southern Massachusetts for the wintering grounds to the westward they drop off along the route anywhere between Rhode Island and North Carolina. Once established in a particular region, many of the fish remain localized for a large part of the winter and do not move far until their return eastward in the spring.

Virtually all the cod from east of longitude 70° W. which survive death or capture after reaching the wintering grounds to the westward and southward of Nantucket Shoals return to New England before or during the spring. Some may return eastward at any time during the winter, but most of them in March and April, and the last stragglers leave New Jersey waters in May. We have as evidence of the return migration the increased catches of cod off New Jersey and New York, made in March and April as compared with January and February, and off Rhode Island in April and May; the recapture during the summer and fall off southern New England of cod tagged off New York and New Jersey the previous winter and spring; the migration to Nantucket Shoals in the spring of cod tagged around Buzzards Bay and at Woods Hole during the winter; and the fact that cod are virtually absent west of Rhode Island during the summer.

MIGRATION OF COD TO THE NORTH AND EAST OF NANTUCKET SHOALS

MIGRATION TO THE CHATHAM-SOUTH CHANNEL REGION

Only about 10 to 40 miles separate the centers of the Chatham-South Channel region from localities on Nantucket Shoals where tagging has been done. (Fig. 12.) Because of this proximity and a considerable amount of commercial fishing which is done on the grounds adjacent to the shoals, it was natural that we should expect many of the Nantucket tagged cod to be recaptured there. But although good returns were had from the Chatham grounds, where the commercial catch has of recent years been small, the recaptures reported from South Channel fell below expectations.

TABLE 18.—*Cod tagged on Nantucket Shoals and recaptured on the Chatham grounds during the years 1923 to 1928*

Tagged during—	Number tagged	Recaptured during the seasons and months shown																
		First season						Second season								Third season		
		June	July	Aug.	Sept.	Oct.	Dec.	Mar.	May	June	July	Aug.	Sept.	Oct.	Nov.	June	July	Aug.
1923	7,514	3	2	5	1	1		1		2		8		1				10
1924	3,105			2						2		6	2		1			
1925	4,010			7	2		1		1			1				1	1	
1926	1,606																	
1927	5,020										1							
1928	973																	

TABLE 19.—*Cod tagged on Nantucket Shoals and recaptured in South Channel during the years 1923 to 1928*

Tagged during—	Number tagged	Recaptured during the seasons and months shown															
		First season						Second season						Third season			
		June	July	Aug.	Sept.	Oct.	Nov.	May	June	July	Aug.	Sept.	Oct.	June	July	Aug.	Oct.
1923 [1]	7,514		2	1	1	1	1		1		1	1	1	1		2	
1924	3,105									1	2	1	1		1		
1925	4,010	1	1	3	1	2		1	1	2	2	1					1
1926	1,606																
1927	5,020			1	1	1				1	1					1	
1928	973						1										

[1] 1 cod was recaptured in October, 1927.

The segregation of recaptures given in Tables 18 and 19 indicate that a fair proportion of the cod living on Nantucket Shoals emigrated to the Chatham-South Channel region during the spring and summer of the years 1923, 1924, and 1925, and that relatively few went there during the three years which followed. The contrast in the magnitude of this emigration during each of the 3-year periods is brought out in Table 20, which consolidates the Chatham and the South Channel recaptures.

TABLE 20.—*The number of tagged Nantucket Shoals cod reported from the Chatham South Channel region during each year from 1923 to 1928*

Tagged on Nantucket Shoals		Recaptured in the Chatham-South Channel region					
Year	Number	1923	1924	1925	1926	1927	1928
1923	7,514	18	16	13	0	1	0
1924	3,105		2	16	1	0	0
1925	4,010			18	9	3	0
1926	1,606				0	0	0
1927	5,020					3	3
1928	973						1
Total		18	18	47	10	7	4

The United States Bureau of Fisheries has collected statistics [10] of the catch of cod taken each month on the Chatham grounds and South Channel so that there is opportunity to make a direct comparison between the total number of fish taken and the number of tagged fish recaptured. These records are listed in Tables 21 and 22.

TABLE 21.—*The reported number of Nantucket Shoals tagged cod taken on the Chatham grounds, from 1923 to 1928 by fishing vessels operating out of Boston, Gloucester, and Portland, together with the catch of cod for each month*

Month	Number of cod taken by the New England fleet and, in parentheses, the catch of Nantucket Shoals tagged cod					
	1923	1924	1925	1926	1927	1928
January	(a)	3,188	4,077	1,855	3,558	40
February	[a] 624	3,752	2,522	7,052	1,042	3,799
March	[a] 3,565	2,336 (1)	9,149	1,643	1,856	1,054
April	11,532	3,606	2,069	6,956	1,637	6,498
May	26,347	4,073	2,169	6,243 (1)	1,619	2,347
June	6,707 (3)	159 (2)	2,810 (2)	1,148	0 (1)	1,045
July	158 (2)	--------	2,249	1,763	164 (1)	130 (1)
August	0 (5)	1,008 (10)	7,317 (23)	780 (1)	--------	--------
September	0 (1)	161	969 (4)	1,115	13	2,534
October	0 (1)	1,170 (1)	564	106	7	--------
November	2,127	--------	707 (1)	1,365	294	228
December	293	1,834	1,774 (1)	377	300	171
Total	51,353 (12)	21,287 (14)	36,376 (31)	30,403 (2)	10,490 (2)	17,846 (1)

[a] The first cod of this investigation were marked in April, 1923, so that statistics prior to then can have no relation to the tag returns.

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[10] The original statistics give the catch of cod in pounds, and the number of fish is estimated here on a basis of 1 fish for each 10 pounds of catch.

TABLE 22.—*The reported number of Nantucket Shoals tagged cod taken in South Channel from 1923 to 1928 by fishing vessels operating out of Boston, Gloucester, and Portland together with the catch of cod for each month*

Month	Number of cod taken by the New England fleet and, in parentheses, the catch of Nantucket Shoals tagged cod					
	1923	1924	1925	1926	1927	1928
January	[1] 17, 803	27, 000	34, 162	50, 920	52, 754	62, 115
February	[1] 23, 866	37, 472	49, 673	40, 675	42, 488	63, 655
March	[1] 26, 658	32, 594	28, 207	60, 429	73, 992	62, 410
April	23, 686	42, 668	40, 331	39, 353	87, 988	59, 249
May	36, 333	31, 673	31, 286	33, 293 (1)	56, 528	32, 613
June	90, 415	70, 905 (1)	85, 449 (2)	83, 665 (1)	67, 693	67, 345
July	169, 367 (2)	88, 961	125, 674 (2)	109, 783 (3)	96, 940	95, 599 (1)
August	164, 197 (1)	147, 454 (1)	155, 831 (7)	124, 287 (2)	202, 296 (1)	247, 083 (1)
September	112, 014 (1)	169, 542 (1)	168, 211 (2)	91, 573 (1)	210, 060 (1)	158, 453
October	91, 613 (1)	140, 069 (1)	70, 818 (3)	135, 190	156, 774 (3)	131, 410
November	58, 745 (1)	48, 569	52, 968	75, 579	107, 983	106, 181 (1)
December	28, 970	29, 645	19, 314	40, 524	67, 853	76, 222
Total	843, 667 (6)	866, 552 (4)	861, 924 (16)	885, 271 (8)	1, 223, 349 (5)	1, 162, 335 (3)

[1] The first cod of this investigation were marked in April, 1923, so that statistics prior to then can have no relation with the tag returns.

The available statistics of the catch of cod taken in the Chatham-South Channel region are not sufficiently complete for the preceding table to give more than a general idea of the relationship between the number of cod caught and the number of tagged cod retaken. For example, the records show no catch of cod on the Chatham grounds for the summer of 1923 or for June, 1927, yet a total of 8 tagged fish were taken there during these periods. (Table 21.) This discrepancy is evidently due to the fact that the Chatham grounds and South Channel merge one into the other, so that boats which fish in this general region might describe their fish as from either place. Yet in spite of this confusion that may obtain from time to time, it is probable that fishermen as a rule do distinguish between the two localities and state their catch correctly as from one or the other.

Only 42 Nantucket Shoals tagged cod were reported among about 6,000,000 cod caught in South Channel from 1923 to 1928, or 1 for each 142,000, whereas 62 were reported from the Chatham grounds among about 167,000 taken there, or 1 out of each 2,700. Direct computation would indicate a concentration of Nantucket tagged cod on the Chatham grounds over fifty times as great as in South Channel. This figure is undoubtedly too high because more tags were overlooked or lost in the channel where otter trawling is the prevailing method of fishing than off Chatham where much line trawling is done. But in spite of this, the small yield of tagged cod in the South Channel region affords rather good evidence that comparatively few Nantucket cod move eastward to the offshore banks.

A comparison of the catches of cod made in the Chatham-South Channel region during the summer and winter seasons of the years from 1923 to 1928 shows a surprising result. On the Chatham grounds only 3 tagged fish were reported among a catch of about 131,000 cod taken from December to May (about 78 per cent of the total catch), whereas from June to November 59 tagged Nantucket cod were reported among a catch of about 37,000 fish (22 per cent of the total catch). In South Channel only 1 tagged cod was reported from December to May among about 1,500,000, while 41 tagged fish were recorded from nearly 4,500,000 cod caught from June to November. This contrast in the numbers of summer and winter recaptures reported from the Chatham-South Channel region was not brought about by chance, for the experiment extended over a period of six years, from 1923 to 1928, and the results were very much the same during each of these years.

It will be noted in Table 20 that nearly all of the recaptures made in the Chatham-South Channel region during 1924 were of fish tagged on Nantucket Shoals in 1923. This suggests that many of the 1923 cod emigrated eastward the spring of 1924, for only two of the cod tagged on the shoals in 1924 were retaken to the eastward that same year, probably because our first tagging was done so late (July) in the season. Conditions seemed to be right for a large return of tagged cod in 1925 because we had marked a large number in 1923 and in the summer and fall of 1924. Some of these were still present on Nantucket Shoals the spring of 1925, and many fish were tagged that year as early as April and May. Thus, there probably were more tagged cod present on the shoals in May, 1925, than during any other period from 1923 to 1928. But although this may partly explain the large return of tags from the Chatham-South Channel region in 1925, the same line of reasoning can not explain the paucity of recaptures from 1926 to 1928.

No obvious cause for the great difference in the numbers of tags reported during these two 3-year periods has been detected. So far as the yield of the fishery is concerned, the catches made during 1923 to 1925 were actually smaller than during 1926 to 1928. This being so, it is evident that the difference in the yield of tags is due not to fishing intensity but to a corresponding difference in the numbers of fish which took part in the migration from the one region to the other.

It is not fully understood why so many tagged Nantucket cod migrated to the Chatham-South Channel region during 1923 to 1925 as compared with the following three years, but there is some indication that temperature, together with the size of the fish which made up the adult population on Nantucket Shoals, was a contributing cause. For example, it is rather well known that large cod tend to work their way into deep water and that they are more susceptible to environmental changes than are small cod. Inasmuch as many of the cod on the shoals in 1923–1925 were upward of 26 to 28 inches long, and very few fish so large were present there during the next three years, it is not at all unlikely that a large part of the former sought the deeper waters of the Chatham-South Channel region. The fact that the summer of 1925, when the greatest number of recaptures was made in the Chatham-South Channel region, was the warmest of the six years makes this all the more likely.

Our experience has been that the cod living on the Chatham grounds and on Nantucket Shoals carry out very much the same migratory schedule, for from both regions some of the fish move to the westward to spend the winter, while others straggle to the northward. But, unfortunately, the number of cod tagged on the Chatham grounds has been too small to throw any light on the question of an intermigration between there and the Nantucket grounds. The decided predominance of the summer recaptures just mentioned seems to indicate that of the Nantucket cod which summer in the Chatham-South Channel region very few remain to spend the winter, but what part of them return westward to the shoals to join the migration into the Rhode Island-North Carolina region and what part go north is not known.

The number of cod which emigrated from Nantucket to the Chatham-South Channel region was not sufficiently large to make a marked impression on the tagging data of the shoals. We found, for example, that even during 1923 to 1925 many of the cod present on the shoals in the spring and early summer were still there in the fall, and also that the abundance of the cod did not diminish during any of these summers. It is very likely that fewer cod were involved in any one of these summer emigrations to the eastward than in any one of the fall migrations to the westward.

This summer migration of cod may be summarized as follows:

1. A summer emigration of cod from Nantucket Shoals to the Chatham-South Channel region occurred each of the years from 1923 to 1925, during which period many of the adult fish on the shoals were more than 25 inches in length, while the emigration was scarcely noticeable from 1926 to 1928, when the fish averaged below this size.
2. According to tagged-fish records, few Nantucket cod move eastward before May.
3. Scarcely any of the Nantucket cod which summer in the Chatham-South Channel region remain there for the winter. Where they go is problematical, but many of them may return westward in the fall either to remain on the shoals or to continue on to the wintering grounds between Rhode Island and North Carolina. A few probably straggle to the northward.
4. During the summers when this emigration occurred the numbers of cod which took part were probably smaller than the numbers of those that went westward each fall to spend the winter.

SCATTERING OF NANTUCKET-CHATHAM COD TO THE NORTHWARD AND EASTWARD

From a total of 22,228 cod tagged on Nantucket Shoals during 1923–1928 and 501 tagged on the Chatham grounds during 1927–28 miscellaneous recaptures were reported as follows:

Tagging year, 1923: 7,514 Nantucket cod tagged; 276 recaptured; of these 7, or 2.5 per cent, were from miscellaneous localities: 1 on Georges Bank, April, 1923; 1 off Gloucester, August, 1923; 1 on Jeffreys Ledge, August, 1923; 1 off Plymouth, November, 1923; 1 off Hampton Beach, N. H., May, 1924; 1 off Portland, June, 1923; and 1 on La Have Bank, April, 1925.

Tagging year, 1924: 3,105 Nantucket cod tagged; 104 recaptured; of these 4, or 4 per cent, were from miscellaneous localities: 2 on Georges Bank, November, 1924, and June, 1926; 1 in Barnstable Bay, May, 1925; and 1 on Stellwagen Bank, March, 1925.

Tagging year 1925: 4,010 Nantucket cod tagged; 143 recaptured. Of these, 11, or 7.7 per cent, were from miscellaneous localities: 1 on Georges Bank, December, 1925; 1 off Highland Light, October, 1926; 3 on Stellwagen Bank, August, 1925, and February and July, 1926; 1 off Marblehead, May, 1926; 1 in Ipswich Bay, May, 1927; 1 in Salem Harbor, July, 1925; 1 off Monhegan, September, 1925; and 2 off Mount Desert, February, 1926, and fall of 1927.

Tagging year 1926: 1,606 Nantucket cod tagged; 18 recaptured. Of these, 1 fish, or 5.5 per cent, was retaken on Georges Bank in May, 1927.

Tagging year 1927: 5,020 Nantucket cod tagged; 149 recaptured. Of these, 5, or 3.4 per cent, were from miscellaneous localities, as follows: 3 on Georges Bank, December, 1927, and September and October, 1928; 1 on Stellwagen Bank, November, 1927; and 1 off Nahant, April, 1928. On the Chatham ground 475 cod were tagged of which 16 were recaptured, 1 of them being in Ipswich Bay in May, 1928.

Tagging year 1928: 973 Nantucket cod tagged; 23 recaptured; none have been reported from localities to the northward or eastward. On the Chatham ground 26 cod were tagged and none was recaptured.

The recapture localities of the Nantucket fish which went to the north and east are shown in Figure 13. Some idea of the amounts of cod caught on certain of these grounds may be had from the following catches landed at Portland, Gloucester, and Boston during the year 1924: Immediate shore waters, from Cape Cod Bay to eastern Maine, 5,000,000 pounds; Stellwagen Bank, 280,000 pounds; Jeffreys Ledge, 1,000,000 pounds; and Georges Bank, 21,000,000 pounds. On Browns Bank, from

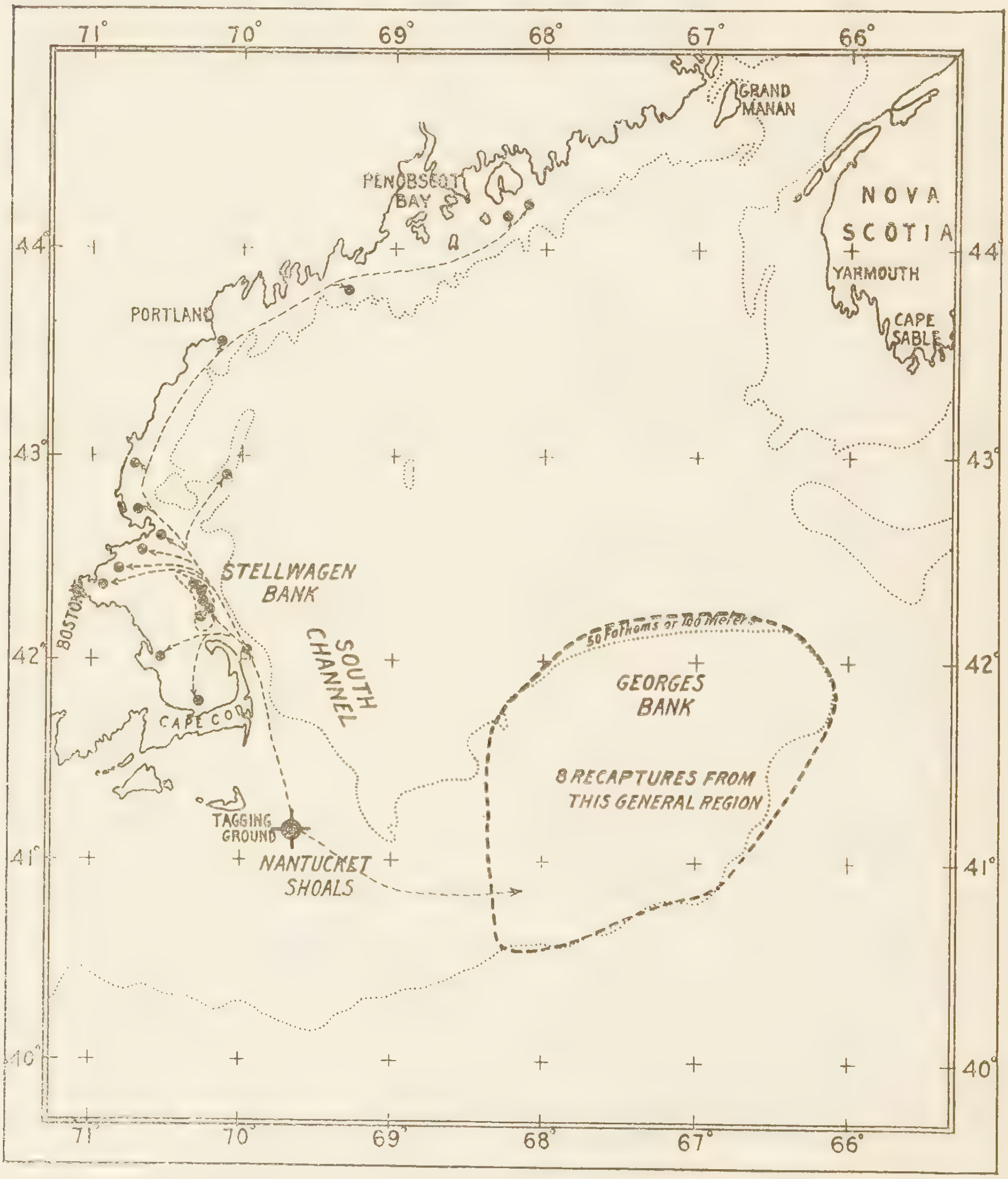
71°
70°
69°
68°
67°
66°
GRAND MANAN
PENOBSCOT BAY
NOVA SCOTIA
YARMOUTH
CAPE SABLE
PORTLAND
44°
43°
42°
41°
40°
STELLWAGEN BANK
SOUTH CHANNEL
BOSTON
CAPE COD
50 Fathoms or 100 Meters
GEORGES BANK
8 RECAPTURES FROM THIS GENERAL REGION
TAGGING GROUND
NANTUCKET SHOALS

FIGURE 13.—Recaptures made to the northward and eastward of Cape Cod (excepting the South Channel region) from 22,228 cod tagged on Nantucket Shoals from 1923 to 1928. Each dot indicates one fish

which no Nantucket-tagged cod have been reported, the catch of cod landed in American ports during 1924 amounted to 5,490,000 pounds.

The foregoing list of recaptures shows that—

1. No seasonal migration of cod took place from Nantucket Shoals to any of these various localities, because the few miscellaneous recaptures were taken during every month of the year except January.

2. On an average only 1 out of 800 cod marked on Nantucket Shoals was reported recaptured to the north and east of Cape Cod. Even allowing for the tag-scarred fish, which were not reported because they were not recognized by the fishermen, the percentage of Nantucket cod which stray to the north and east is very small according to the tag records.

3. According to the limited amount of tagging done on the Chatham grounds, this region, too, contributes only a small part of its cod to the northward and eastward.

4. It is evident that most of those fish which do migrate north and east of Nantucket Shoals, Chatham, or South Channel follow a route along the shore from Chatham to Maine. The only offshore records we have are 8 for Georges Bank and 1 for La Have. It would be interesting to know the route of the latter. The recaptures of Nantucket fish at various points along the coast of northern New England suggest that the La Have fish followed the shore route rather than that it crossed Georges and the deep channel that separates the latter from the Scotian Banks.

The 8 Georges Bank recaptures of Nantucket-tagged cod just mentioned are so few that they constitute further evidence that most of those cod which do migrate north from the shoals select the shore rather than the offshore route, and they give some indication as to why so few recaptures in the face of intensive fishing were reported from the South Channel region, namely, that relatively few cod migrate eastward from Nantucket Shoals to the offshore grounds.

The many unknown factors having to do with the migrations and behavior of the cod, together with the element of chance which always plays a large part in our fisheries, make it unwise to give too much credence to these numerical data. For example, it is probable that the loss of tags tends to reduce the number of returns from northern localities more than from the local or the western migration recaptures of Nantucket cod because the time intervals in the former average somewhat longer than for the latter. But even so, we are justified in saying that on the basis of tag returns over a period of six years only a relatively small proportion of the stock of Nantucket-Chatham cod move to regions east or north of the Chatham grounds and South Channel each year.

COD WHICH GAVE NO EVIDENCE OF MIGRATING

In all previous cod-tagging experiments it has been found that a large part of the fish marked remained for a period of months or years in the immediate locality where they were released. Most of these fish were taken within the first few months, before enough time had elapsed for them to lose their tags, but of those which retained their tags some were retaken as much as a year or more later. Thus many of the cod tagged off the mouth of Buzzards Bay during the winter by Smith (1902) remained near by until spring, when they migrated eastward to Nantucket Shoals, which is the nearest year-round cod ground. And in European waters many of the cod tagged in the North Sea off the Faroes and around Norway and Iceland were recaptured months later without having shown a migration of more than a few miles.

We expected, then, that many of the cod which were tagged on Nantucket Shoals and elsewhere along the New England coast would remain localized for some time, although we could not be sure that fish would remain from one year to the next or for longer periods. However, as the following records show, many of the cod tagged off southern Massachusetts were recaptured a long time later in the same place where they had been released.

LOCALIZATION AS SHOWN BY TAGGED FISH

WOODS HOLE REGION

In this locality, as already stated, cod are present throughout the winter, but most of them go eastward to spend the summer. Cod tagged by Smith (1902) remained near by from early winter to late spring (Table 2, p. 7); and of the cod tagged in January on the present investigation 2 were recaptured near by in August, Table 15, and several of the fish taken in the fall probably remained throughout the year almost on the very spot where they were tagged. In this category may be placed the 2 cod tagged off No Mans Land and recaptured there one and two and a half years later, respectively (p. 25). It is possible that these fish could have summered on Nantucket Shoals, but if they did the chance of their being recaught in the same place where they were tagged appears to be remote.

NANTUCKET SHOALS

Our most extensive data on the localization of the cod come from Nantucket Shoals, where so many fish have been marked and recaptured, so that from these ample proof has been obtained that some cod remain in this region throughout the summer, or from one year to the next. A record of all those cod which were both tagged and recaptured on Nantucket Shoals is given in the table which follows.

TABLE 23.—*Cod tagged on Nantucket Shoals and subsequently recaptured on Nantucket Shoals* [1]

Tagged		Recaptured																			
		1923						1924							1925						
Date	Number	June	July	August	September	October	November	April	May	June	July	August	September	October	April	May	July	August	September	October	November
1923:																					
Apr. 19–May 4	244			1					1		1										
May 23–27	424		1	2		5			1		1										
June 22–28 [2]	1,144	1	4	4	1	21					2		1	1							
Aug. 16–19 [2]	1,795			1	9	7	1			1	1				1						
Sept. 5–11	1,354				2	7	1				1		1				1	1			
Oct. 3–17	2,552					5		1			6		3	4			2	1			
1924:																					
July 13–17	1,254										1	2	6	3					1		
Sept. 6–12	964													11		2		4	1	1	
Oct. 16–28 [3]	887															1		3		2	
1925:																					
May 5–8	854																	6	1	5	
June 7–12	672																1	2	3	3	
Aug. 20–25	1,158																			5	1
Oct. 1–6, 24–30	1,325																			1	

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[1] The months of December, January, February, and March are not included in these tables because very little fishing is done on Nantucket Shoals during the winter, so that at that season there is little opportunity for recapturing tagged fish.

[2] 1 cod was recaptured in December, 1923.

[3] 1 cod was recaptured in January, 1925.

TABLE 23.—*Cod tagged on Nantucket Shoals and subsequently recaptured on Nantucket Shoals*—Continued

Tagged		Recaptured																			
		1926						1927							1928			1929			
Date	Number	June	July	August	September	October	November	May	June	July	August	September	October	November	July	September	October	May	June	August	October
1924:																					
Sept. 6–12	964			1									1								
1925:																					
May 5–8	854	1	1																		
June 7–12	672	1			1	1	1														
Aug. 20–25	1,158			1	2	1						1									
Oct. 1–6, 24–30	1,325	3	2		4	2			2												
1926:																					
Sept. 5–11	1,606						1	1	1			1	1								
1927:																					
May 4–7	1,083								6		2	6	3	4	6						
June 17–25	1,497									1		5	1			4	2				
Aug. 31, Sept. 3	1,264												1	2	2	1					
Oct. 14–17	1,176															1	1		1	1	
1928:																					
July 13–21	693																2	1			1
Oct. 24–29	280																		1		

The recaptures given in Table 23 prove conclusively that part of the cod living on Nantucket Shoals one summer are to be found there a year or more later. A few tagged fish were retaken on the shoals in the winter, in contrast to the lack of recaptures at that time in the Chatham-South Channel region, where a large number of cod were caught. That the number of tagged fish taken monthly did not follow more closely the fluctuations in the commercial catch (Table 24) was due to the fact that much depended upon what part of the shoals the fishermen were operating. Very often a large proportion of the cod were caught along the eastern edge of the grounds by haddock fishermen and the number of cod tags received from this source was small. We have here a good indication that many of the cod living on the shoals remain localized for an extended time. This is shown further by the comparison between the number of marked fish taken by the tagging vessels, which, of course, fished on the tagging grounds, with that taken by commercial fishermen who generally fished about 10 to 40 miles away. Throughout the period from 1923 to 1928 the *Halcyon* and the *Albatross II* recaptured on the shoals proper 122 Nantucket cod with tags attached, among about 24,000 cod caught, whereas commercial fishing boats reported only 137, among a catch of about 866,000. To make this difference more striking, the time element between the dates of tagging and recapture was very much the same for the fish retaken by fishermen and those retaken by us. The average number of days the fish recaptured by us were at liberty was 72 in 1923, 232 in 1924, 193 in 1925, 336 in 1926, 246 in 1927, and 378 in 1928. Thus it can be seen that sufficient time had elapsed for these fish to have emigrated to other regions if they had so desired.

TABLE 24.—*The reported number of Nantucket Shoals tagged cod taken on Nantucket Shoals from 1923 to 1928 by fishing vessels operating out of Boston, Gloucester, and Portland, together with the catch of cod for each month*

Month	Number of cod taken by New England fleet and, in parentheses, number of Nantucket Shoals tagged cod [1]					
	1923	1924	1925	1926	1927	1928 [2]
January	--------	1,947	3,775 (1)	582	1,931	364
February	1,666	--------	--------	--------	847	323
March	--------	--------	--------	--------	364	659
April	--------	0 (1)	7,298 (1)	--------	364	9,192
May	3,331	5,327 (2)	35,194 (1)	7,582	1,759	28,355
June	16,968	12,129 (1)	12,108	7,456 (5)	706	12,387
July	28,260 (5)	40,718 (4)	6,704 (4)	18,375 (3)	15,615 (1)	9,897 (1)
August	21,677 (5)	9,866 (2)	25,939 (10)	15,227 (2)	14,970	35,811
September	52,805 (12)	4,965 (2)	3,041 (6)	12,274 (4)	19,678 (2)	44,269 (6)
October	32,768 (17)	33,693 (5)	15,261 (6)	26,847 (4)	19,638 (7)	104,202 (4)
November	2,276 (2)	9,187	17,900 (1)	17,090 (2)	10,177 (6)	4,966
December	516 (2)	8,619	1,528	2,728	777	5,268
Total	160,267 (43)	126,451 (17)	128,748 (30)	108,161 (20)	86,826 (16)	255,693 (11)

[1] These statistics were obtained from monthly bulletins, giving the catch landed by vessels in Boston, Gloucester, and Portland, issued by the Bureau of Fisheries. The number of fish is estimated here on a basis of 1 fish for each 10 pounds of catch.

[2] In addition to the recaptures reported for 1928 there were taken on Nantucket Shoals 2 Woods Hole tagged cod (1 in March 1 in October), 1 Cholera Bank cod in May and 1 Atlantic City cod in July.

More proof that cod remain on Nantucket Shoals for an extended period is had from the records of catch, per unit of effort, made by the *Halcyon* and the *Albatross II*, which show that throughout the summer, at least, the cod population was very stable. This is shown in Table 25.

TABLE 25.—*The catch of cod made by the tagging vessels on Nantucket Shoals from April to October, 1923–1928 per unit of effort* [1]

Month	Cod caught						Catch of cod per hour on a basis of six lines fishing					
	1923	1924	1925	1926	1927	1928	1923	1924	1925	1926	1927	1928
April 17–May 3	282	--------	--------	--------	--------	--------	8.3	--------	--------	--------	--------	--------
May [2]	487	--------	879	--------	1,251	--------	10.1	--------	25.1	--------	65.0	--------
June	1,278	--------	718	--------	1,705	--------	27.8	--------	21.4	--------	38.6	--------
July	--------	1,420	--------	--------	--------	748	--------	30.8	--------	--------	--------	16.0
August	1,970	--------	1,292	--------	--------	--------	47.0	--------	41.6	--------	--------	--------
September	1,454	1,063	--------	1,911	1,460	--------	25.5	30.8	--------	33.6	42.0	--------
October [3]	2,730	955	1,441	--------	1,294	304	38.4	15.0	38.0	--------	44.5	8.7

[1] This table includes all cod caught whether or not they were tagged. It should be remembered that pollock and haddock were caught with the cod, so that the catch of fish per hour was greater than the figures for the cod alone.

[2] Fishing was done the last week of May, 1923, and the first week of May, 1925.

[3] Two cruises were made during October each year from 1923 to 1925.

It can be seen that the catch of cod was most uniform throughout the summer months, while the greatest fluctuations took place in the fall and spring, at which seasons, respectively, cod were departing from and returning to Nantucket Shoals from their wintering grounds to the westward. It is possible that the stock of fish would be kept fairly constant if cod emigrated during the summer and were replaced by new immigrants. But as few Nantucket tagged cod have been retaken to the north and east of the grounds off southern Massachusetts at any time, it is quite evident that the summer population retains its numerical strength chiefly because most of the fish remain localized.

Certain of the extreme catches given in the preceding table can be explained, at least in part. Thus the small catch made on the first cruise in 1923, which was the first to be made on the present investigation, might be laid partly to our unfamiliarity of the best fishing grounds. The large catch made in May, 1927, was due to the presence near Round Shoal buoy—one of our chief tagging grounds—of a dense school of medium-sized cod. They probably extended over a large part of Nantucket shoals, for cod were more plentiful on all of our tagging grounds off Nantucket during 1927 than during any of the other years.

The wide fluctuations in the October catch are of interest because it is during this month that the westward migration commences. Thus it would seem that in October, 1924, a large part of the fish had already started westward at the time we fished the shoals. In October, 1928, this was still more apparent, for although during the early and middle parts of the month there occurred one of the best catches of cod on the shoals ever made by commercial vessels (Table 24, p. 44), fish were relatively scarce at the time we fished there during the end of the month.

While we can not be sure that the results obtained on the tagging grounds hold for all of Nantucket Shoals, it is very likely that they represent the conditions over a large part. Numerical data dealing with the catch of fish per unit of effort should always be interpreted broadly, because chance is always an important factor in the finding of fish, especially when only one vessel is operating, and some variation in the catch would occur from this cause alone even though the stock of fish remained virtually the same as to numbers from month to month or from year to year.

Other evidence that cod remain localized on Nantucket Shoals for an extended period is shown by the time sequence and the tag-number sequence of the recaptures, for it was noted that many of the marked fish were retaken in almost identically the same place where they had been tagged and that often when one fish was recaught others would follow soon after as long as we fished the same ground.

Thus the *Halcyon* recaptured 6 cod on August 20, 1925, at Round Shoal buoy by drifting repeatedly over a small spot about one-half mile long during two and one-half hours of actual fishing. These recaptures were taken at the following minutes of the day: 3, 3.15, 3.25, 3.35, 3.40, and 4.10 p. m. Five of these fish had been tagged at Round Shoal buoy the previous May and June. In contrast to this we fished 20 miles to the southward, around Great Rip, from August 23 to 25, for 18 hours, and caught about 1,000 cod, among which there was not one tagged fish. The reason for this was apparent, for we had not tagged any cod at Great Rip since 1923, whereas several thousands of fish had been tagged around Round Shoal buoy between October, 1923, and June, 1925; hence the good return of tagged fish which we obtained there in August, 1925. Not only does this show that a large part of the fish remained on the shoals but that they did not move far from the immediate vicinity of the tagging grounds, else we probably would have caught some of them around Great Rip.

Another case of this sort occurred at Round Shoal buoy on October 3, 1925, when seven hours' actual fishing was done there and 6 tagged cod were recaptured by the *Halcyon*, as follows: 8.20, 8.30, 10.40, 10.45, 10.50 a. m., and 1.30 p. m. All these fish had been tagged at Round Shoal buoy between April, 1924, and August, 1925, on four different cruises.

Other instances of this kind were found not only on Nantucket Shoals but on other grounds in the Gulf of Maine as well. Off the coast of Maine in particular, where we have tagged and recaptured many cod close to shore, and thus could take precise bearings on our tagging localities, there were many instances where tagged fish were recaught in rapid succession and often of nearly consecutive number. There is a good example of this off Petit Manan, east of Mount Desert, Me., where on July 13, 1925, we tagged 168 cod and on July 14, 226 cod. Returning there on September 14, 1925, the *Halcyon* recaptured 9 of the cod tagged on July 14, but none of those tagged on the 13th. Although fishing was done off Petit Manan most of the day on September 14, 8 of the recaptured tagged fish were taken within the space of 22 minutes and the ninth was taken about an hour later, as follows: 1, 1.10, 1.15, 1.17, 1.17, 1.20, 1.21, 1.22, and 2.15 p. m.

The tag-number sequence of recaptures points to the localization of the cod perhaps even better than do the time sequences, for if cod of nearly consecutive tag numbers are recaptured months later, on the same date and in the same place, we can be reasonably certain that such fish belonged to a school which held together during the interim.

TABLE 26.—*Records of Nantucket Shoals cod of nearly consecutive tag numbers which were recaptured on the same or nearly the same day in the same locality where they were tagged*

Tagged at Round Shoal buoy	Recaptured at or near Round Shoal buoy	Tag numbers
June 24, 1923	Oct. 6, 1923	10708, 10768.
June 28, 1923	Oct. 3, 1923	231, 309, 336.
Do	Oct. 4, 1923	277, 303.
Do	Oct. 15, 1923	248, 231, 283, 375.
Do	Oct. 24, 1923	232, 272.
Aug. 17, 1923	Sept. 3, 1923	558, 627.
Aug. 18, 1923	Sept. 17, 1923	916, 917, 919.
Oct. 15, 1923	July 13-16, 1924	486, 491.
May 4, 1927	Sept. 3, 1927	47472, 47499.
May 6, 1927	June 17-27, 1927	47778, 47977, 48053, 48075, 48087, 48090.
Do	Sept. 1-3, 1927	47738, 47856, 48022, 48155, 48328.
Do	Oct. 8, 1927	47801, 47803, 47809.
Do	Nov. 16-19, 1927	47776, 47944, 48020, 48025,
June 18, 1927	Sept. 1-2, 1927	49103, 49141, 49247.

Most of the recaptures given in Table 26 were taken by the tagging vessels, but in a few cases commercial fishermen made the catch. Examples were selected only from the tagging years 1923 and 1927, because we had opportunity to tag and recapture more cod on Nantucket Shoals those years than any of the others. However, each of the years from 1923 to 1928 produced virtually the same result as regards the close association of the individuals making up various small schools of cod.

Those cod retaken (by the *Halcyon*) in October, 1923, as a result of the tagging done the preceding June, show how stationary the fish must have been on Nantucket Shoals that summer. The May, 1927, cod recaptured November 16–19, 1927, are particularly interesting, for they are the latest group of fall recaptures to be taken on the shoals. It is possible these fish did not migrate over the winter; but that part of the May, 1927, cod had already gone westward, is shown by the recapture on November 16 to 21, 1927, of 4 cod of this same school (Nos. 47545, 47715, 47854, and 48324) off northern New Jersey. It will be noted that the recapture dates of these latter fish coincide with those of the fish retaken on the shoals just mentioned, and it is also noteworthy that, as all of them were tagged on May 6, 1927, the body of fish to which they belonged must have held together rather well, in spite of the fact that they had traveled westward about 200 miles. Other examples of this could be cited.

Another interesting point bearing on the localization of Nantucket cod during the summer is furnished by the records of cod which were recaptured more than once. Such records were made possible because all of the 120 cod retaken and again released on the shoals by the tagging vessels were liable to be recaught a second time. Those fish which fell in this category are listed in Table 27.

TABLE 27.—*Tagged cod that were recaptured more than once*

Tag number	Date of tagging on Nantucket Shoals	First recapture, Nantucket Shoals	Second recapture and locality
231	June 28, 1923	Oct. 3, 1923	Oct. 15, 1923, Nantucket Shoals.
277	do	Oct. 4, 1923	Jan. 5, 1924, Rockaway, N. Y.
12017	Aug. 16, 1923	Oct. 6, 1923	Jan. 2, 1924, Rockaway, N. Y.
18674	July 15, 1924	Oct. 27, 1924	Dec. 7, 1924, Cholera Bank, N. Y.
21216	Sept. 8, 1924	May 6, 1925	Aug. 7, 1925, Nantucket Shoals.
21380	Sept. 11, 1924	Oct. 18, 1924	Sept. 12, 1925, Nantucket Shoals.
28015	May 5, 1925	Aug. 20, 1925	Oct. 27, 1925, off Great Point, Nantucket Island.

The additional check given by these "second" recaptures throws further light on the behavior of Nantucket Shoals cod. Thus we have cod Nos. 21216 and 21380, whose recapture records indicate that they may have spent the winter on the shoals without having migrated westward, for they were caught three times in the same immediate locality; and cod Nos. 277, 12017, and 18674, which, although they did winter in the New York region, nevertheless spent the summer, up to at least October, on the shoals. It is of interest to note that although cod No. 28015 was recaptured locally, both on August 20 and on October 27, the last recapture being off Great Point, was at the extreme western part of the shoals—an indication that this fish had begun its migration into the Rhode Island-North Carolina region.

THE CHATHAM GROUNDS

Although only a small number of cod were tagged on the Chatham grounds, several of them were recaptured a sufficient time later to indicate that part of the stock of fish spent the summer there without migrating away. (See Table 16 on p. 27.) So, although no tagged Chatham ground cod were recaptured locally during the winter or during the summer which followed, this is perhaps due to the small number of fish that were marked, coupled with the inevitable loss of tags rather than to all the fish having moved away.

LOCALIZATION AS SHOWN BY LENGTH FREQUENCY DISTRIBUTIONS

Up to this point we have discussed the localization of cod on Nantucket Shoals as shown by tagged fish. Although this method has thrown considerable light on the movements of the cod, it has been found possible to corroborate and even to amplify the results obtained from tagged fish by an analysis of length-frequency distributions.

It is obvious that if the relative proportion of fish of different lengths on a certain ground varies from month to month, or from year to year, not in accord with the normal growth schedule, either some age classes have been locally depleted or others reinforced. Consequently, we may hope to trace the movements of bodies of fish onto or away from any given bank, or the interchange of schools between different banks, by analyzing the length frequencies of unselected catches taken at intervals.

We concentrated our tagging, therefore, on certain parts of Nantucket Shoals (fig. 14), for by so doing it was possible to detect slight changes in the lengths of any given body of fish and also to learn whether many of them emigrated away or whether new immigrants had appeared in the locality in question.

The lengths [11] given in the following graphs (figs. 15 to 24) were taken from cod caught by the *Halcyon* and the *Albatross II*, including all those that were tagged plus some which were injured and killed. It is not possible to say how nearly these hook-caught fish are representative of the population, but there is no apparent reason to doubt the adequacy of the samples for the purposes of the present study, at least for the sizes large enough to take the hook readily.

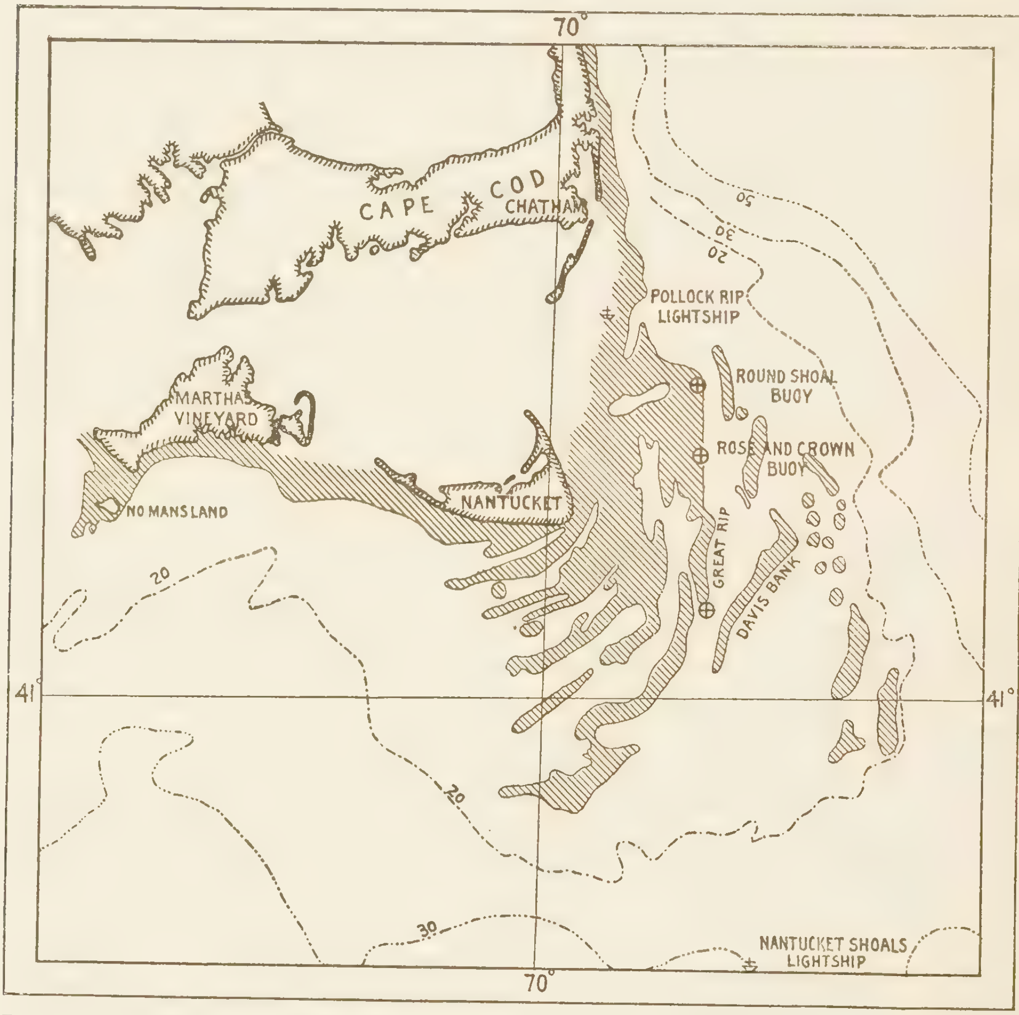
70°
CAPE COD
CHATHAM
50
30
20
POLLOCK RIP LIGHTSHIP
ROUND SHOAL BUOY
MARTHAS VINEYARD
ROSE AND CROWN BUOY
NANTUCKET
NO MANS LAND
GREAT RIP
DAVIS BANK
20
41°
41°
20
30
NANTUCKET SHOALS LIGHTSHIP
70°

FIGURE 14.—The three buoys on Nantucket Shoals—Round Shoal, Rose and Crown, and Great Rip—around which much of the cod tagging was done. The shaded areas represent depths of less than 10 fathoms

Our length frequencies start from 1923, the first year of the present investigation. Prior to then no lengths for cod caught on Nantucket Shoals were available, so that we had no means of knowing what a normal year might be or how the sizes would fluctuate. That they did fluctuate is shown in Table 28.

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[11] All the fish were measured to within the nearest quarter inch and grouped in inch classes, those at the half inch being included with the next highest inch; that is, 20½ to 21¼ inches were classed as 21 inches

Table 28.—*Size distribution of all the cod caught on Nantucket Shoals during tagging operations 1923–1929*

Length in inches	Per cent at each length							Length in inches	Per cent at each length						
	1923	1924	1925	1926	1927	1928	1929		1923	1924	1925	1926	1927	1928	1929
Below 14	------	0.1	0.6	------	0.1	0.7	------	30	7.8	5.7	5.0	1.1	1.9	1.2	2.8
14	0.1	.4	1.3	0.1	.1	1.5	0.0	31	5.0	6.0	3.3	.4	1.1	1.1	1.3
15	------	.6	1.8	1.0	.1	1.9	.6	32	3.6	5.3	2.0	.4	.7	.5	2.7
16	.1	.8	1.9	4.3	.3	1.5	2.7	33	2.5	2.8	1.6	.4	.6	.4	.4
17	.3	.7	1.9	13.0	.7	2.2	8.8	34	2.0	2.7	1.2	.4	.5	.3	.6
18	.5	.4	3.4	17.9	2.1	5.2	10.2	35	1.6	1.6	1.0	.1	.5	.4	.2
19	1.2	.7	6.6	15.8	6.4	5.7	9.4	36	1.3	1.1	.8	.1	.4	.0	.0
20	1.7	1.3	8.0	10.9	13.3	6.7	7.2	37	.6	.9	.4	.0	.1	.3	.3
21	2.3	2.3	9.0	6.0	17.6	7.1	4.0	38	.6	.2	.6	.1	.1	.0	.2
22	2.5	5.4	9.6	4.3	15.9	8.0	6.2	39	.3	.1	.3	.0	.1	.0	.0
23	2.6	10.0	5.0	3.6	12.1	10.7	8.2	40	.3	.2	.3	.0	.1	.0	.0
24	3.9	11.4	3.8	4.7	8.0	11.6	10.0	Above 40	.6	.5	.7	.0	.1	.2	.4
25	7.6	12.8	4.1	5.6	5.7	11.9	6.0								
26	11.6	9.0	5.6	4.6	3.7	8.9	5.5	Total	100.0	100.0	100.0	100.0	99.7	99.7	100.1
27	13.9	6.0	7.0	2.7	2.5	6.3	4.3								
28	13.4	5.5	7.4	1.3	2.6	3.4	4.4	Number measured	7,554	3,102	4,142	1,878	5,712	1,042	704
29	12.1	5.5	5.8	1.2	2.3	2.0	3.7								

One point which stands out in this table is the small number of cod below 16 inches and above 32 inches in length. The scarcity of the small fish in our catches was due in some degree to the selectiveness of the hook-and-line gear. However, using this same gear along the coast of Maine, we have caught many cod as small as 11 inches and a few of 10 inches in length; hence it would appear that our failure to catch small fish on Nantucket Shoals, except at rare intervals indicates either that they are not present or that their feeding habits differ from cod inhabiting the more northern waters. The latter is not likely. With regard to the larger fish, there are strong indications that they tend to move into deeper water and that their scarcity on Nantucket Shoals is not due entirely to the local fishing.

It will be noted that each year from 1923 to 1929 certain size groups were dominant, as, for example, the 26 to 29 inch group in 1923, the 23 to 26 inch group in 1924, etc. The causes for the progressive decline in the dominant sizes which occurred annually from 1923 to 1926 and the progressive increase which occurred thereafter afford an interesting problem. The decline appears to have been caused by the emigration of fish away from and the immigration of new fish to the shoals, while the increase resulted from the growth registered by the same school of cod which occupied the Nantucket grounds for at least three years. These changes will be taken up in detail.

As an aid to a better understanding of the graphs and text which follow, each of the six outstanding schools of cod found on Nantucket Shoals from 1923 to 1929 is designated by a symbol (*A*, *B*, *C*, *D*, *E*, or *F*).

The term "stock" of fish is meant to cover the entire population inhabiting the region in question. "School," "group," "age class," and "length class" are used almost synonymously to refer to one particular part of the fish population, such as the *A* group in Figure 15. In this case it is obvious that while one age class is outstanding among the *A* fish there is an overlapping of younger and older fish and the term "group" or "school" should not be interpreted to refer to only one age class. As the analysis of the length frequencies given here is made chiefly to determine the migrations of bodies of cod and changes in the population on the various tagging grounds, age and rate of growth are mentioned only when necessary as an aid in understanding the data. These important subjects "age" and "rate of growth" are discussed in a later chapter.

LENGTHS OF NANTUCKET SHOALS COD IN 1923

On all the grounds fished by us during 1923 very much the same frequency distribution was obtained, indicating that one school of cod covered a good part of the shoals. It was not until October that on one of the tagging grounds the length distribution was altered somewhat by the appearance of a body of small fish (fig. 15, No. 1, symbol *B*) which had not been noted from April to September. The *A* fish centered around 26 to 28 inches on all the grounds and at Great Rip the 29-inch size was included in addition.

The fact that the length-frequency distribution of the Nantucket Shoals cod remained rather constant throughout the summer of 1923 suggests that relatively few immigrants arrived during that season, else the frequencies would probably have altered materially. And as the catch of fish taken by the *Halcyon* per unit of effort did not fall during the summer, it appears that the emigration of Nantucket cod to the Chatham-South Channel region, already referred to, involved a relatively small part of the population.

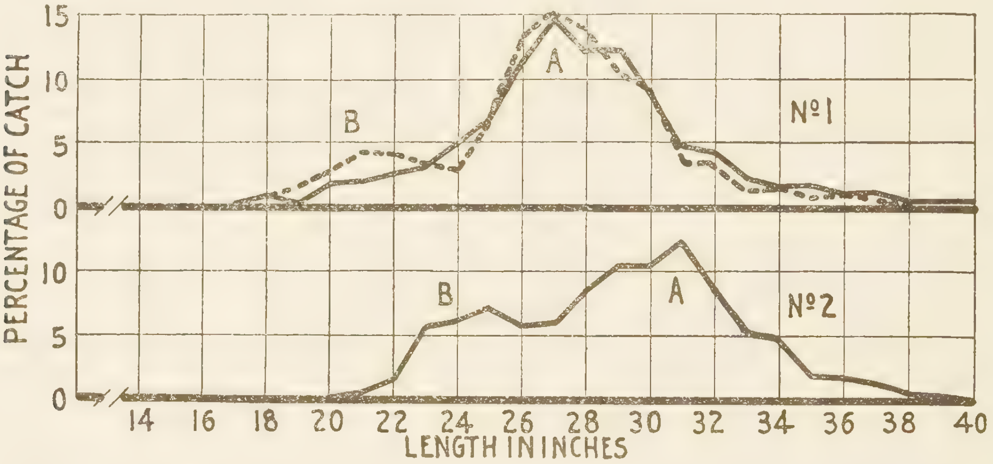

FIGURE 15.—*No. 1*=length-frequency distribution of 1,144 cod caught at Round Shoal buoy June 22–28 (solid line), and 1,071 caught October 3–6, 1923 (broken line). *No. 2*=length-frequency distribution of 788 cod caught 5 to 12 miles ESE. of Round Shoal buoy July 14–16, 1924

LENGTHS OF NANTUCKET SHOALS COD IN 1924

The first cruise in 1924 was not made until July. Two localities were fished at that time, namely, the Round Shoal buoy grounds where we tagged throughout 1923 and a new tagging ground situated 5 to 12 miles east-southeast from this buoy.

We noticed at once that the lengths of the cod taken in July, 1924, differed considerably from those obtained during any month or on any tagging ground during 1923. (Figs. 15 and 16.)

At Round Shoal buoy cod of the *A* group had disappeared, their place being taken by what can be recognized as the *B* group, now centering around 23 to 25 inches, evidently having grown to this size since the previous season when it was last seen at 20 to 22 inches. But on the new tagging ground, 5 to 12 miles east-southeast of Round Shoal buoy, however, the catch was dominated by the *A* group (fig. 15, No. 2), which had increased in length since the summer of 1923. Unfortunately, no tagging was done in 1923 on the grounds east-southeast from Round Shoal buoy; but it would seem that many of these *A* group fish had moved to there, as indicated by the recapture of the *Halcyon*, 12 miles east-southeast of Round Shoal buoy, of a

31-inch cod which had been tagged when 29 inches long in August, 1923, in the immediate vicinity of the buoy. Furthermore, many of the cod tagged in 1923 on Nantucket Shoals were subsequently recaptured during 1924 and 1925 a little to the eastward on the Chatham grounds and South Channel. And to show that it was chiefly this predominating size group which carried out this eastern migration we have the following data: 5,015 fish, or 66.4 per cent of the total of 7,554 cod caught on Nantucket Shoals in 1923, were 25 to 30 inches in length (*A* cod), while 23 fish, or 74.2 per cent of the total of 31 recaptures made on the Chatham grounds and in South Channel, from June, 1924, to August, 1925, were of cod which measured 25 to 30 inches on Nantucket Shoals in 1923.

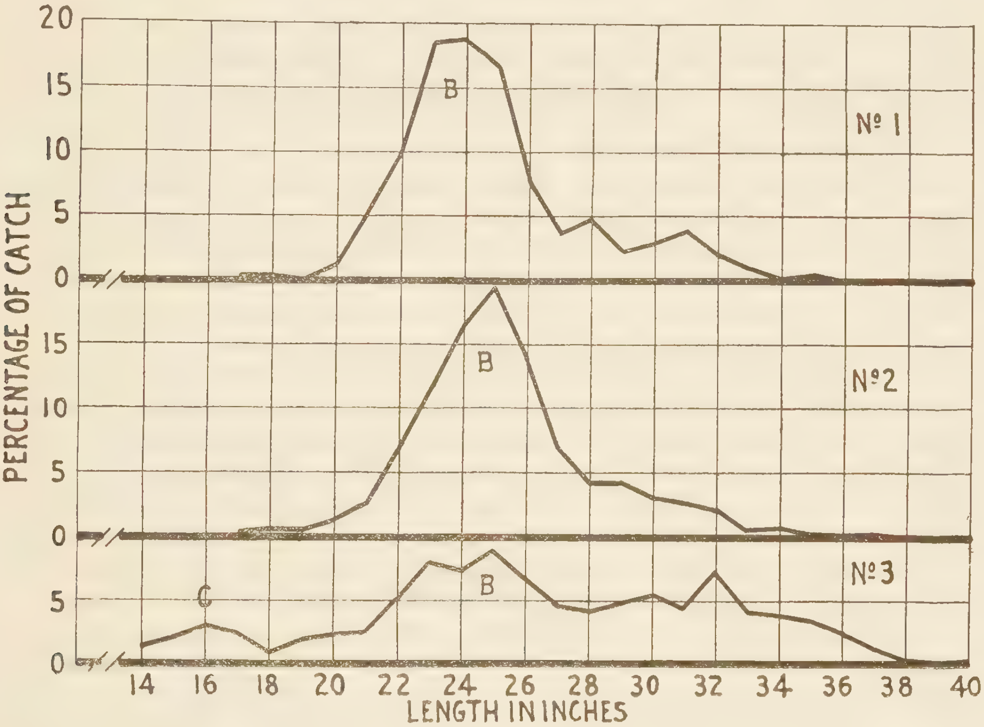

FIGURE 16.—*No. 1*=length-frequency distribution of 466 cod caught at Round Shoal buoy July 13–17, 1924. *No. 2*=length-frequency distribution of 964 cod caught from Round Shoal buoy to Rose and Crown buoy, September 6–11, 1924. *No. 3*=length-frequency distribution of 795 cod caught from Round Shoal buoy to Rose and Crown buoy, October 16 to 28, 1924

With this evidence we can conclude that most of the individuals belonging to this great school of fish (1923 *A* cod) immigrated to the Chatham-South Channel region some time between the fall of 1923 and the summer of 1924, for they were not observed on Nantucket Shoals thereafter. Many of them probably migrated westward in the fall of 1923, the survivors of this migration returning to Nantucket Shoals in the spring and continuing eastward toward the Chatham grounds. Almost all the fish above 33 inches likewise left the Round Shoal buoy grounds over the winter of 1923–24, for they were not present there the summer of 1924.

The 20 to 22 inch fish, *B*, which first appeared in October, 1923 (fig. 15, No. 1), evidently immigrated to Nantucket Shoals in large numbers some time during the winter of 1923–24, for on our July cruise we found that they formed the predominating group at Round Shoal buoy. (Fig. 16, No. 1.) They had grown to 23 to 25 inches during the interim. That these fish belonged to the same school present the preceding fall is indicated by the *Halcyon's* recapture at Round Shoal buoy in July, 1924, of 12 cod 23 to 25 inches long, 5 of which measured 19 to 23 inches long when tagged there in 1923. Apparently this 23 to 25 school, *B*, was a large one, for even on the grounds 5 to 12 miles east-southeast of the buoy they were abundant enough to stand out in the length-frequency distribution (fig. 15, No. 2), although they were greatly exceeded in numbers by the 28 to 32 inch cod that were presumably moving eastward.

On the cruise made September 6 to 11, 1924, most of the fishing was done on the grounds extending from Round Shoal buoy to Rose and Crown buoy. Practically the same size distribution was obtained from the 298 cod caught at the Round Shoal buoy grounds as from the 637 caught between the buoys, so the total catch of 964 fish from both localities are combined in the graph. (Fig. 16, No. 2.) On the grounds 6 to 8 miles east-southeast of Round Shoal buoy the remnant of the 1923 *A* cod present in July, 1924, had seemingly disappeared by September, as only a few scattering fish were taken there at that time.

It is apparent that the 23 to 25 inch July cod (fig. 16, No. 1) were predominant on the tagging grounds in September; but at that time, due to increased growth, they were 23 to 26 inches long. (Fig. 16, No. 2.) Small fish were absent and large fish above 33 inches were still scarce. The picture was, therefore, almost exactly the same as obtained at Round Shoal buoy in July, 1924, and illustrates how stationary the cod must have been throughout the summer.

Two successive cruises were made to Nantucket Shoals within the period October 16–28, 1924, and, as shown by Figure 16, No. 3, the size distribution which obtained in July and September was very much altered. Whereas the July and September length frequencies showed that no important immigration or emigration of cod occurred to or from Nantucket Shoals throughout the summer (unless a school of cod migrated to or from Nantucket Shoals and had the same length frequencies as the fish already on the shoals; such an instance is possible but not probable, as our data have shown), the October distribution showed that migrations of some sort were taking place, otherwise such a disturbance in the sizes of the cod present would not have occurred. The 23 to 26 inch *B* cod of July and September still formed a large part of the stock of fish present from Round Shoal to Rose and Crown buoys in October, but at least two other schools of cod had appeared in this region. One of them was comprised of 15 to 17 inch cod and will be designated as *C* fish. These, although apparently few in number, were destined to form a very important part of the stock of fish on Nantucket Shoals in 1925. The other school was a somewhat heterogeneous lot of large cod centering around 30 to 32 inches, some of which were present previously. The presence in October of these latter two size groups naturally tended to reduce the proportion of *B* cod considerably below that which was present in September. The departure of some of the *B* cod to the westward would also have reduced their percentage in the total stock of fish.

The appearance in October of these two schools of cod (15 to 17 inches and 30 to 32 inches, fig. 16, No. 3) agreed with the results of our cod tagging the year before, which showed that cod school up and migrate to the westward of Nantucket Shoals in the fall. It is possible that the cod centering around 30 to 32 inches may have been a return of part of the *A* fish which predominated on Nantucket Shoals in 1923 and which last were traced to the east-southeast of Round Shoal buoy in July, 1924 (fig. 15, No. 2), or they may have come from some part of the shoals where no tagging had been done and from where, therefore, no length frequencies had been obtained. It is more likely, however, that the cod centering around 30 to 32 inches, as well as the 15 to 17 inch fish, *C*, came from grounds north or east of the shoals, because we learned in the years which followed 1924 that at least a small part of the cod living on Stellwagen Bank, Georges Bank, and particularly in the Chatham-South Channel region join in the fall migration to the westward of Nantucket Shoals.

Around Great Rip buoy and Davis Bank 89 cod were taken in October—too few to show graphically. There were, however, no small fish present, and a predominance of sizes, irregularly distributed between 25 and 34 inches, suggesting that some of the Round Shoal *B* cod (23 to 26 inches) as well as of the school of uncertain identity (30 to 32 inches) extended that far south on the shoals.

The year 1924 in summary:

The dominant size group of cod, *A*, present in 1923 on all the Nantucket Shoals tagging grounds left the Round Shoal-Rose and Crown buoy grounds some time before July, 1924, and they were found to be traveling eastward toward the Chatham-South Channel region during that month. The *B* cod which first appeared on the Round Shoal buoy grounds in October, 1923, formed the dominant group on the various Nantucket Shoals tagging grounds throughout the summer of 1924. They appeared in large numbers some time between October, 1923, and July, 1924, but just when we can not say surely, as no fish tagging was done within this period. Very likely most of them migrated to and occupied the Nantucket Shoals grounds before the close of 1923. The stock of cod inhabiting the shoals throughout the summer of 1924 carried out no migrations that included large numbers of fish, nor were their numbers augmented materially during that period, but during October, 1924, a school of cod that was apparently on its way westward to spend the winter appeared on the tagging grounds. Some of these very likely remained on Nantucket Shoals throughout the winter and did not continue westward.

LENGTHS OF NANTUCKET SHOALS COD IN 1925

No track was kept of the cod on Nantucket Shoals during the winter of 1924–25 nor during any of the other winters throughout our tagging operations. We are obliged, therefore, to jump from the fall to the next spring or summer in taking up the analysis of the length frequencies.

In preparing the length data for our May cruise to Nantucket Shoals in 1925 the Round Shoal to Rose and Crown region was subdivided into three areas—one being within about a mile of Round Shoal buoy, another in the vicinity of Rose and Crown buoy, and the other between the two buoys, which were about 6 miles apart. Very much the same length frequencies were obtained from each of these areas, excepting that a slightly greater proportion of larger fish was taken around Rose and Crown buoy, and, because there was no important difference, all the lengths were combined in the same graph. (Fig. 17, No. 1.)

This first cruise to the shoals was particularly interesting, for there was some speculation as to whether the small cod below 20 inches in length, which first appeared the preceding October, would still be there in the spring. It will be remembered (fig. 16, No. 3) that in October, 1924, a small peak was formed by the 15 to 17 inch fish, *C*, which sizes comprised 7.4 per cent of the total catch of cod. This same stock of fish, *C*, was present on the shoals in the spring of 1925 and apparently was augmented by additional immigrants. Due to growth, the 15 to 17 inch October, 1924, cod were 18 to 20 inches long in May, 1925, and these sizes formed 29.7 per cent of the total catch of cod. (Fig. 17, No. 1.) The tagging locality in May, 1925, was the same as that where all the fish given in Figure 16, No. 3 (October, 1924), were taken, namely, Round Shoal buoy to Rose and Crown buoy. The 23 to 26 inch cod, *B*, which comprised a major group in October, 1924, were present on the same tagging grounds and in about the same proportion. They had, of course, grown in length and the 23-inch fish were fading out of the picture while the 24 to 27 inch lengths dominated.

The second cruise to Nantucket Shoals in 1925 was made in June and the size distribution is given in Figure 17, No. 2.

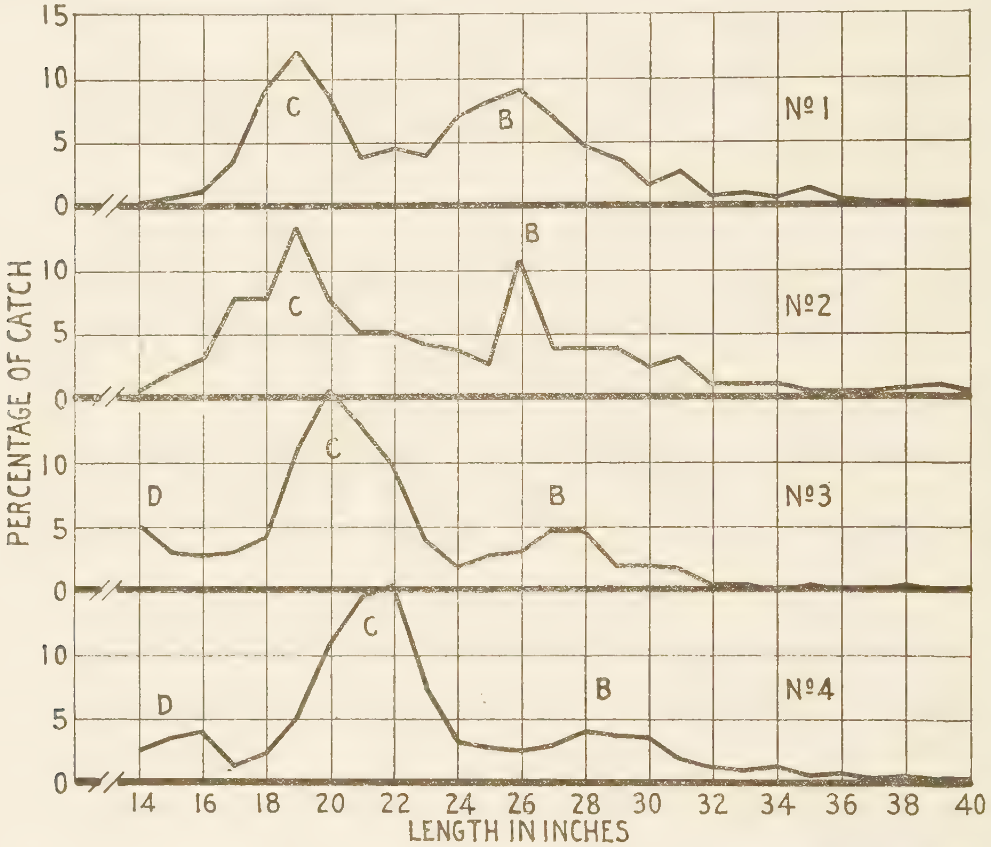

FIGURE 17.—Length-frequency distribution of cod caught between Round Shoal buoy and Rose and Crown buoy. *No. 1*=852 fish taken May 5–8, 1925. *No. 2*=154 fish taken June 7–12, 1925. *No. 3*=253 fish taken August 21–25, 1925. *No. 4*=1,330 fish taken October 1–6 and October 24–30, 1925

Most of the fishing in June was 6 to 12 miles east-southeast of Round Shoal buoy on the grounds where the last of the *A* cod were found in July, 1924. Enough cod were caught in the immediate vicinity of the buoy, however, to show that in June the same 18 to 20 inch school, *C*, had remained from the previous month (fig. 17, No. 2) and apparently no migration occured in the meantime.

The 24 to 27 inch fish, *B*, so plentiful in May, 1925, were represented in June chiefly by the 26-inch size. The number of cod caught in June, however, was too small to draw conclusions other than that the stock of cod around Round Shoal buoy was essentially the same as in May.

The stock of cod 6 to 12 miles east-southeast (fig. 18, No. 1) differed in their length frequencies from those living in the immediate vicinity of the buoy, for we found (1) that the 18 to 20 inch fish, *C*, so dominant at the buoy were barely discernible to the east-southeast, while (2) the 25 to 28 inch fish, *B*, weakly represented by 26-inch fish at the buoy, were the dominant group to the east-southeast. A good proportion of larger fish above 28 inches also were present east-southeast of the buoy; and, though the group was not well enough defined to indicate its origin, it is not improbable that many of them were from the *A* group that were traced to this locality in 1924. The 25 to 28 inch cod, *B*, were apparently the same school which inhabited the east-southeast grounds in July, 1924 (fig. 15, No. 2), when they were 23 to 26 inches long. This, together with the fact that there was a marked decrease in the proportion of *B* cod present on the Round Shoal buoy grounds in June, 1925, as compared with May, indicated that this school moved eastward between early May and early June to join the fish already living on the grounds 6 to 12 miles east-southeast. This same sort of migration occurred in 1924, when our *A* fish were traced to these grounds. The results obtained in August, which follow, likewise favor this theory.

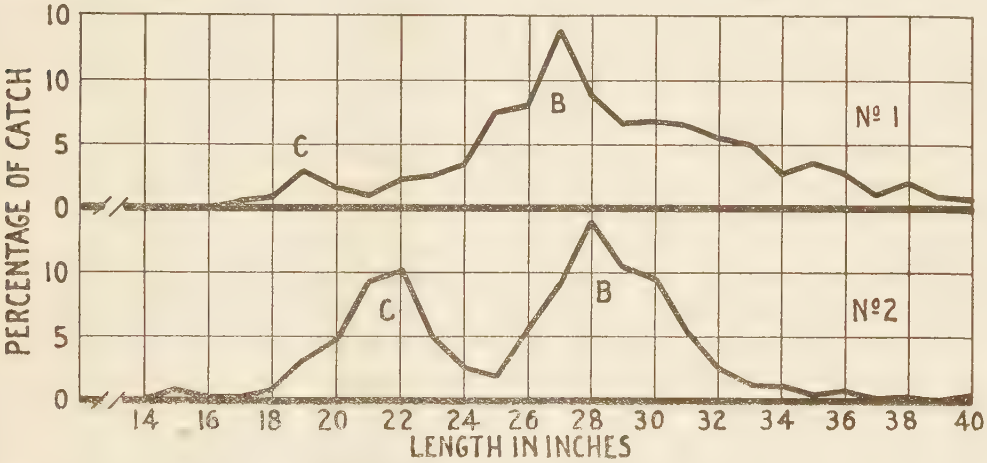

FIGURE 18.—*No. 1*=length-frequency distribution of 517 cod caught 6 to 12 miles ESE. of Round Shoal buoy June 7–12, 1925. *No. 2*=length-frequency distribution of 1,038 cod caught at Great Rip buoy August 21–25, 1925

Fishing was restricted to the grounds near Round Shoal buoy and Great Rip buoy on our next cruise to Nantucket Shoals, August 21–25, 1925.

The *C* school, which predominated at Round Shoal buoy in June, 1925, with a peak at 19 inches, was still the dominant group in August, but the peak had moved to 20 inches (fig. 17, No. 3), doubtlessly, because the fish increased that much in length. The *B* school which was on the wane from May to June, 1925, formed a still smaller part of the stock of fish near Round Shoal buoy by August. The sharp peak at 26 inches in June, 1925 (fig. 17, No. 2), had flattened and centered around 27 to 28 inches by August, due partly to increased growth and partly to the larger sample of fish obtained the latter month. It is apparent from the results of our fishing in May, June, and August that the *B* cod were leaving the Round Shoal buoy grounds. As it was during this time that an emigration of tagged cod occurred from Nantucket Shoals to the Chatham-South Channel region, and as *B* cod were dominant east-southeast of the buoy in June, 1925, and were still well represented at Great Rip buoy in August, 1925, it is apparent that they moved from Round Shoal buoy in an east-to-south direction. A new school of cod, *D*, appeared at Round Shoal buoy in August, 1925, and the sizes of its individuals formed a small peak at 14 inches. If these small cod had passed out of the picture by October they would scarcely deserve passing mention, but it happened that they were the forerunners of the most dominant group of cod, including the largest number of individuals, of any school found on Nantucket Shoals during the years 1923–1929. There were, then, three distinct schools of fish on the Round Shoal buoy grounds—the dominant C school, the B school of secondary importance and fading out of the picture, and the *D* school just forming and destined to become the greatest of all within the next two years.

The first fishing on the Great Rip grounds in 1925 was not started until August. Unfortunately, no cod were tagged there during 1924, so that we have fewer data to compare than for the Round Shoal-Rose and Crown region. We found, however, that the *C* cod were of secondary importance, the *B* cod were dominant, and the *D* cod had not yet appeared. (Fig. 18, No. 2.)

It will be noted that the length frequencies of the *B* and the *C* cod at Great Rip do not coincide with those of Round Shoal buoy, and the question might justly arise as to whether too much dependence is being placed on the length frequencies alone as a means of identifying these schools of fish. While the *B* cod differ very little, the peak of the Great Rip *C* cod lies between 21 and 22 inches instead of between 20 and 21 inches, as at Round Shoal. A similar situation was found to exist in 1926, when 18-inch cod were present at Round Shoal and 20-inch cod at Great Rip (fig. 19), but an analysis of scale samples of these fish showed that the difference in length was caused by an increase in the rate of growth due probably to a more abundant food supply at Great Rip rather than to a difference in age (p. 58).

During October, 1925, two cruises were made to Nantucket Shoals, the first from the 1st to the 6th and the second from the 24th to the 30th. On each of these cruises fishing was restricted to the Round Shoal to Rose and Crown grounds.

Although we could have reasonably expected some differences between the length-frequency distribution of the late October fish as compared with that of the fish taken earlier in the month, due to emigrations and immigrations which are apt to occur at that time, the lengths were very much the same on both cruises; hence, they have been combined in Figure 17, No. 4. There were, however, somewhat fewer cod present late in October, for whereas a catch of 40 fish per hour per unit of effort was made early in the month only 30 fish per hour were taken the end of the month. This indicated that some of the cod had already started westward by October 24. If cod from east or north of Nantucket Shoals were migrating westward by the end of October there were not enough of them on the Round Shoal grounds at the end of October to materially affect the length-frequency distribution which had obtained since the preceding August. A comparison of Figure 17, No. 3, with Figure 17, No. 4, will show how remarkably stable the stock of fish was from summer to fall.

The year 1925 may be summed up as follows:

On the Round Shoal to Rose and Crown grounds the stock of cod was so much the same from month to month that there can be no question but what the major part of the fish, as we found them on our first cruise in May, remained in the immediate vicinity of these tagging grounds throughout the spring, summer, and fall. Briefly, the outstanding features of this stock of fish were that the *C* cod remained predominant throughout the period from May to October; the *B* cod, although present at all times, consistently declined in dominance from May to October; and, a new school of cod, *D*, appeared for the first time in August, 1925, and was still present in October.

On the grounds 6 to 12 miles east-southeast of Round Shoal buoy, where we fished only once during 1925, the *B* cod formed the chief part of the stock of fish. A lack of comparable data for these grounds, such as we have for the Round Shoal to Rose and Crown grounds, precludes a worth-while discussion based on Figure 18, No. 1, alone. The recapture of an unusually large proportion of the Round Shoal to Rose and Crown tagged cod to the southeast and northeast (Chatham and South Channel) during the summer, together with the waning of the *B* cod on these grounds, indicates that the *B* cod were dominant 6 to 12 miles east-southeast because they had moved eastward from the western part of Nantucket Shoals.

At Great Rip buoy, where tagging was done only in August, practically the same stock of cod was present as in the Round Shoal to Rose and Crown region, excepting that the *B* cod were much more prominent.

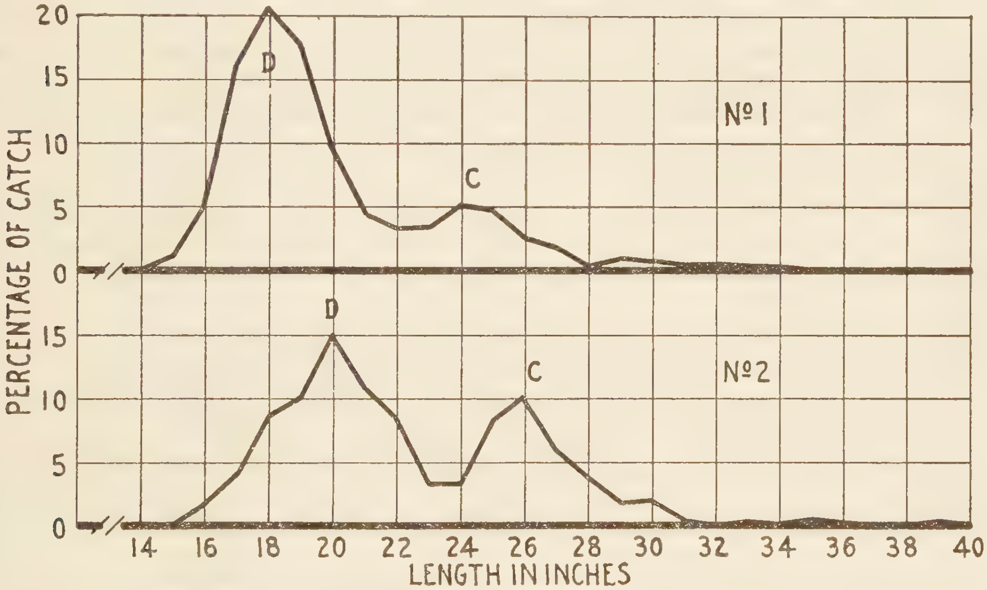

FIGURE 19.—*No. 1*=length-frequency distribution of 1,395 cod caught from Round Shoal buoy to Rose and Crown buoy September 6–11, 1926. *No. 2*=length-frequency distribution of 483 cod caught at Great Rip buoy September 6–11, 1926

LENGTHS OF NANTUCKET SHOALS COD CAUGHT IN 1926

Only one cruise was made to Nantucket Shoals in 1926, but a good sample of the cod living in the Round Shoal to Rose and Crown region (1,395 fish) and around Great Rip (483 fish) was obtained. It was found in September that the Round Shoal to Rose and Crown *B* cod which declined in dominance throughout 1925 were entirely eliminated from the picture, and the *C* cod which were predominant throughout 1925 were now relegated to secondary importance. (Fig. 19, No. 1.) The *D* cod had forged ahead into first place, in fact, comprised about four-fifths of all the fish.

At Great Rip buoy virtually the same stock of cod was present as around Rose and Crown and Round Shoal buoys, about 14 to 20 miles to the northward. Even the *B* cod, so dominant at Great Rip in August, 1925 (fig. 18, No.2), had disappeared from there by September, 1926 (fig. 19, No. 2). The *C* cod which in August, 1925, averaged about 1 inch longer than the Round Shoal *C* cod had increased their dominant lengths from 21 to 22 to 25 to 26 inches.

The *D* cod formed the dominant school at Great Rip in September. The fact that they averaged about 2 inches greater in length than the Round Shoal fish caused some speculation as to whether the fish from these two regions belonged to a homologous group, particularly as no *D* fish were found at Great Rip the preceding August. The problem appeared to be whether or not the 18-inch Round Shoal to Rose and Crown cod were the same age as the 20-inch Great Rip cod. It seemed entirely possible that if the Great Rip fish found more and better food over an extended period than the Round Shoal fish they could have amassed a net gain of about 2 inches in length in about a year's time.

Fortunately, scale samples of all these fish had been obtained, so that by a study of these it was possible to see if such a growth was registered. As the smaller size group, *D*, made up the larger part of the stock of cod at both Round Shoal and Great Rip Bouys, the scales of these fish were examined, but time was not taken to compare the *C* Round Shoal cod with the supposedly *C* Great Rip cod.

Taking them in the order of their tag numbers, the scales were studied of the first 50 Round Shoal cod that measured 16½ to 19¼ inches (which sizes are rated at 17 to 19 inches on the graphs), and the first 50 Great Rip cod that measured 18½ to 21¼ inches (19 to 21 inches on the graphs), thus including the dominant group of *D* cod in each locality. All these fish proved to be between 2 and 3 years of age, except 2 Round Shoal and 1 Great Rip fish. In addition to these lots of scales another, consisting of 49 fish from Round Shoal, 18½ to 21¼ inches long, was compared with the Great Rip fish of the same size. The first two lots of scales are given in the table which follows:

TABLE 29.—*A comparison in the number of peripheral circuli formed on the scales of certain cod living at Great Rip and Round Shoal buoys, Nantucket Shoals, during the summer of 1926*

Round Shoal buoy			Great Rip buoy		
Length in inches	Number of fish	Average number of peripheral circuli	Length in inches	Number of fish	Average number of peripheral circuli
16½–16¼	5	5.4	18½–18¾	6	6.6
17–17¾	17	5.2	19–19¾	19	8.6
18–18¾	18	5.7	20–20¾	20	8.6
19–19¼	8	6.6	21–21¼	4	8.7
Total	48	5.6	Total	49	8.4

As all these fish were of the same age, as measured in years, if would matter little if the larger fish (19 to 21 inches) had hatched a few months before the smaller ones (17 to 19 inches) because the scales of all of them began the formation of the "summer" rings at about the same time during 1926. Therefore, if circuli indicate growth the greater number formed at the periphery of the Great Rip scales is a good indication that these fish were growing at a faster rate than the Round Shoal fish. Even the 18½ to 21¼ inch Round Shoal cod (which may be considered the fastest growing of the *D* fish at Round Shoal) averaged only 7 peripheral circuli as compared to 8.4 for the Great Rip fish of the same size (which may be considered as average growing *D* fish at Great Rip.)

Further evidence that Great Rip cod grow somewhat faster than Round Shoal cod is indicated by the Round Shoal *C* cod, which centered around 24 inches in September, 1926, as against 26 inches for the Great Rip fish (fig. 19), and by the *D* cod, which in June, 1927, had a peak at 21 inches at Round Shoal compared with 22 inches at Great Rip (figs. 20 No. 1, and 22 No. 2). We are justified, therefore, in considering the 19 to 21 inch Great Rip cod and the 17 to 19 inch Round Shoal fish as parts of the same group (*D* cod, fig. 19).

During 1926, therefore, the stocks of cod at Great Rip and at Round Shoal buoy were essentially the same and had in common the following:

1. A complete absence of small cod below 14 inches, excepting those too small to take the hook and concerning whose presence we have only meager information.
2. An almost complete absence of large cod of more than 34 inches in length.
3. Two outstanding size groups of fish—a dominant group composed of 2-year olds (in their third year) averaging about 18 inches long at Round Shoal buoy and around 20 inches long at Great Rip buoy, and a group of secondary importance, composed presumably mostly of 3-year olds, averaging around 24 to 25 inches at Round Shoal buoy and 26 inches at Great Rip buoy. The difference in size in each instance was due most probably to the rate of growth of the fish within their respective areas.

LENGTH OF NANTUCKET COD IN 1927

The first cruise to Nantucket Shoals in 1927 was made early in May, at which time, 1,159 cod were caught.

At no time since we began our cod tagging in April, 1923, did one size group stand out so prominently as on this cruise. (Fig. 20, No. 1.) It was apparent, too, that the 20-inch peak of May, 1927, and the 18-inch peak of September, 1926 (fig. 19, No. 1), were formed by the same stock of fish, with the difference in size being due to growth.

A few scales of these 20-inch May, 1927, cod, *D*, were examined and they proved to have three annual rings as expected in place of the two annuli plus the wide peripheral circuli possessed by the September, 1926, 18-inch fish. Even more positive proof was furnished by the scales of recaptured fish. It so happened that in May, 1927, only one September, 1926, cod was recaptured with its tag still attached (other September, 1926, Nantucket Shoals cod were recaptured by us in June and September, 1927). This fish, which was 19½ inches long and possessed two annuli in September, 1926, was 22¼ inches long and had three annuli in May, 1927.

The *C* cod of September, 1926, were practically out of the picture in May, 1927, as there was then only a bare suspicion of them at 26 inches. A very few large cod, above 34 inches, were present in May, 1927, at Round Shoal buoy (fig. 20, No. 1), although they were absent in 1926. They might have represented part of a school of cod which came from Georges Bank or elsewhere to join the cod migrating westward toward New Jersey in the fall. But it was surprising that the stock of cod in May, 1927, was so nearly like that of September, 1926—the only changes of note being the disappearance of the *C* cod and appearance of a few large fish.

At Great Rip buoy only 93 cod were caught in May, 1927, the small catch being due to weather conditions and other factors rather than to a scarcity of fish. Ordinarily so few fish would be insufficient upon which to draw conclusions, but in the present instance we can be justified in utilizing the September, 1926, and June, 1927, catches at Great Rip to interpret conditions there in May. (Fig. 22, No. 2.)

It appeared, therefore, that the 22 to 23 inch cod, *D*, caught in May were of the same stock that were 20 inches long in September, 1926. (Fig. 19, No. 2.) It will be noted, also, that the 2-inch advantage in length which the Great Rip fish possessed in September, 1926, over the Round Shoal cod remained the same in May, 1927. The *C* school of cod which formed a good part of the total stock of fish at Great Rip in September, 1926, was practically out of the picture in May, 1927, just as it was at Round Shoal buoy.

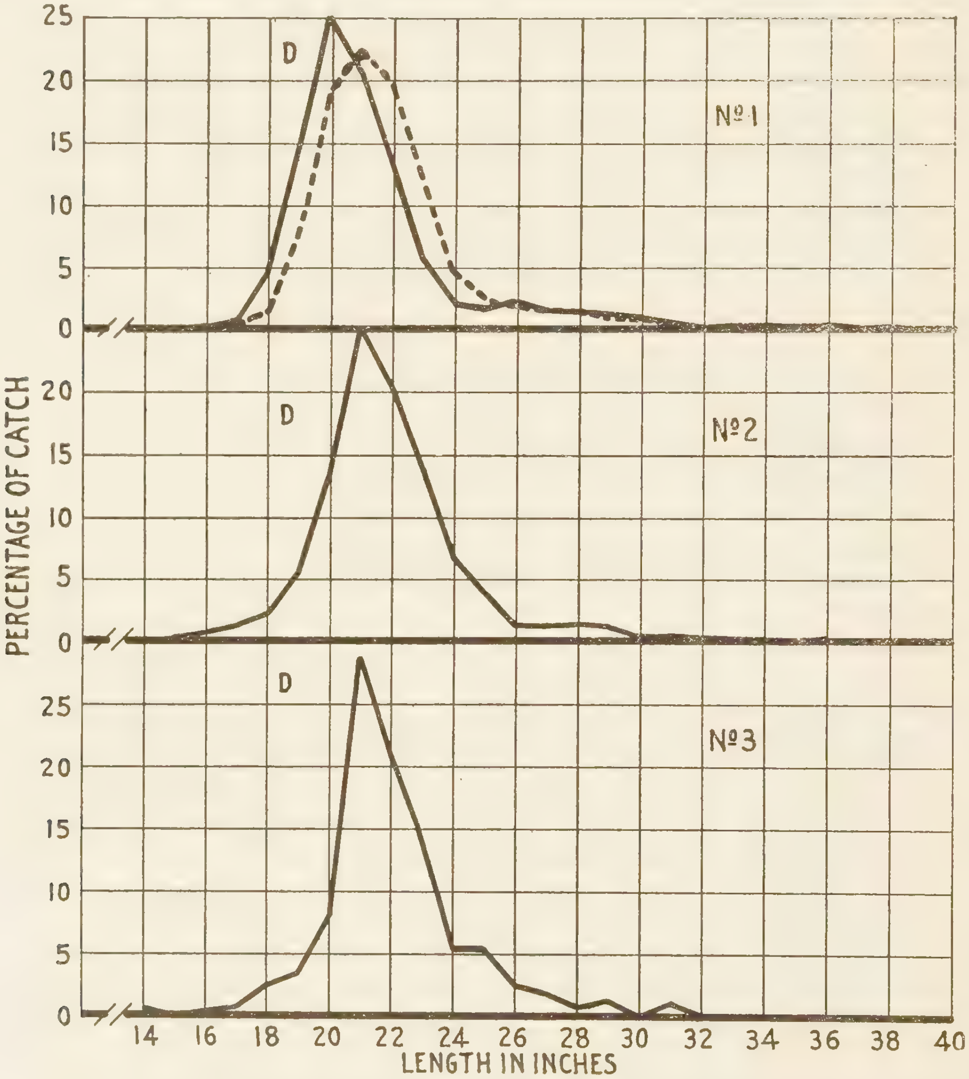

FIGURE 20.—Length-frequency distribution of cod caught between Round Shoal buoy and Rose and Crown buoy. *No. 1*=1,159 fish taken May 4–7 (solid curve) and 878 fish taken June 16–25, 1927 (broken curve). *No. 2*=1,468 fish taken August 31 to September 3, 1927. *No. 3*=275 fish taken October 14–17, 1927

Tagging on the Chatham grounds for the first time during the present investigation was done in May, 1927. It was interesting to find that there, as on the Round Shoal buoy grounds, the *D* cod, with a peak at 20 inches, formed the dominating school. (Fig. 21.) They were not, however, as sharply defined as were the

Round Shoal cod, owing to the presence of larger fish, for whereas only a small percentage of the fish exceeded 24 inches long at Round Shoal buoy an appreciable percentage did so on the Chatham grounds. In the latter locality the small peak at 26 inches suggests that the Round Shoal *C* cod of September, 1926, may have migrated over the Chatham grounds and that a remnant of them were left behind. Or it may be that the *C* cod were present in large numbers on the Chatham grounds in 1926 and that the few present in May, 1927, were a remnant left behind after the others had departed.

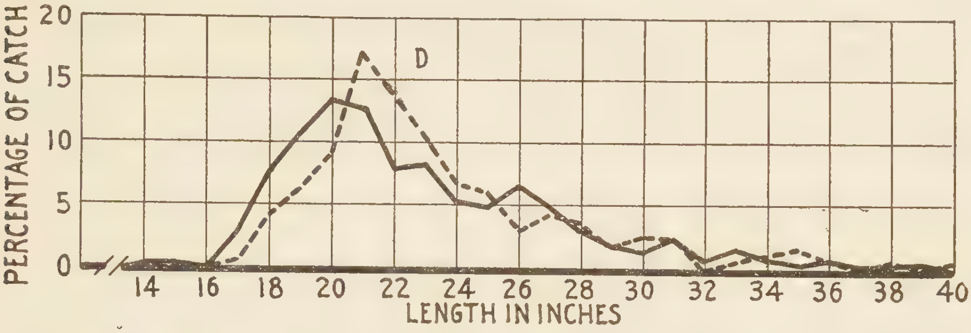

FIGURE 21.—Length-frequency distribution of 299 cod caught on the Chatham grounds, about 12 miles ENE. of Round Shoal buoy, May 3–4 (solid curve), and 161 caught June 16, 1927 (broken curve)

As a result of the fishing just described, it was found that the same school of cod which was dominant on Nantucket Shoals in 1926 was even more so in May, 1927, extending from Round Shoal buoy to at least 10 or 12 miles east-northeast on the Chatham grounds and about 20 miles southward to Great Rip buoy.

The second cruise to Nantucket Shoals in 1927 was made in June. The length frequencies of the cod caught then were almost identical to those taken in May at all three localities—Round Shoal buoy, Great Rip buoy, and the Chatham grounds.

At Round Shoal buoy the great peak of 20 inches in May had been flattened very slightly and stood at 21 inches in June (fig. 20, No. 1), due to growth of the fish. All the large fish above 32 inches had moved away, probably to deeper water.

At Great Rip the *D* cod were dominant at 22 to 24 inches, compared to 20 to 22 at Round Shoal. (Fig. 20, No. 1, and 22, No. 2.) The curve for June is smoother than that of May because a much larger sample of fish was taken, but virtually the same stock was present both months.

On the Chatham grounds the May and June distribution is likewise very much the same, with the 20-inch peak moved over to 21 inches due to growth (fig. 21), just as occurred at Round Shoal buoy.

Tagging also was done east of Davis Bank in June, 1927, and, although we had no previous data with which to compare, it is evident that the *D* cod extended to that region. (Fig. 22, No. 1.) Davis Bank lies about equidistant from Round Shoal and Great Rip buoys, and it was interesting to find that while the *D* cod were 20 to 22 inches on the Round Shoal grounds and 22 to 24 inches on the Great Rip grounds they were 20 to 23 inches on Davis Bank. Whether it was water temperature or food which caused the small differences in the size of the cod living on these three grounds, the intermediate position of Davis Bank appears to connect up the conditions existing on the other two.

On the next cruise to Nantucket Shoals we fished from August 31 to September 3, 1927, chiefly in the vicinity of Round Shoal and Rose and Crown buoys where 1,468 cod were caught. Unquestionably the *D* cod were still present and fully as dominant as in May and June. The peak still remained at 21 inches at Round Shoal buoy (fig. 20, No. 2), indicating that the fish had not grown appreciably during the interim from late June to the end of August.

It is hard to understand why the fish showed an increase of 1 inch in length from May to June and only about three-fourths inch from June to August—a period when we could have expected them to grow fully as fast as during the spring. Yet the frequency distributions as shown by Figure 20 show rather conclusively that we are dealing with the same stock of fish.

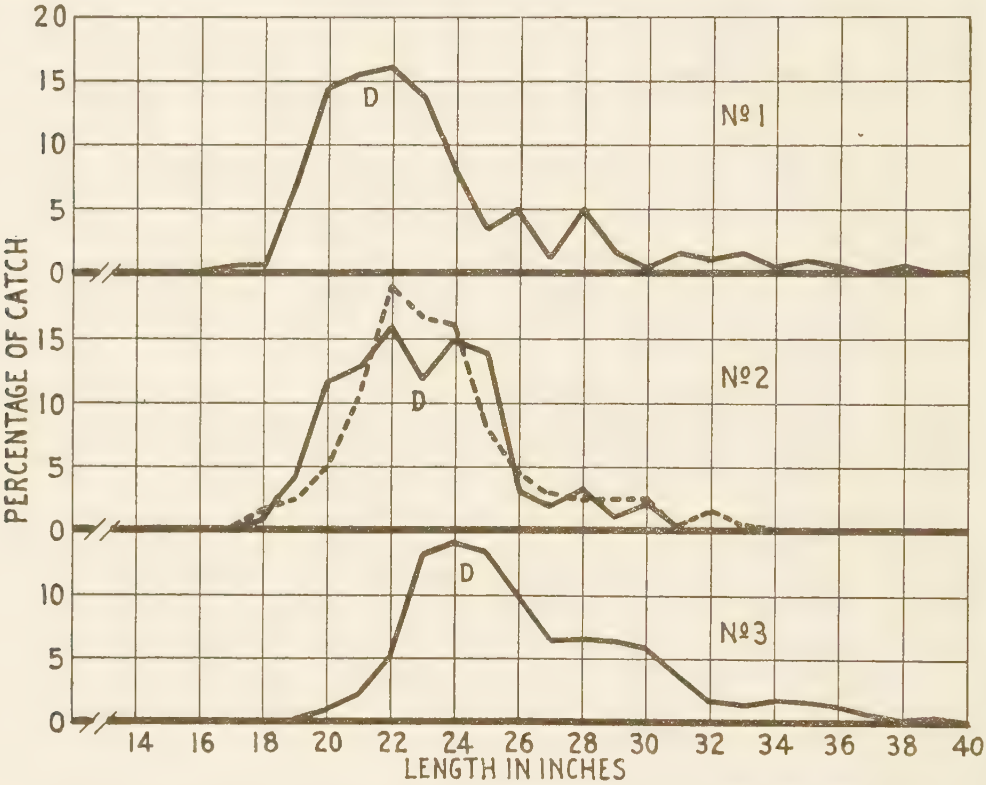

FIGURE 22.—*No. 1*=length-frequency distribution of 180 cod caught 15 miles SE. by E. from Round Shoal buoy June 17, 1927. *No. 2*=length-frequency distribution of 93 cod caught off Great Rip buoy May 4–7 (solid curve) and 643 caught June 16–25, 1927 (broken curve). *No. 3*=length-frequency distribution of 1,016 cod caught at Great Rip buoy October 15–17, 1927

During very limited fishing on the Chatham grounds 38 cod were caught on September 2—too few to show graphically—but it is significant that 10 of these belonged to the 21-inch class, indicating that the *D* cod were still the dominant school there as they were in May and June.

The last cruise to Nantucket Shoals in 1927 was made in October, when fishing was done from the 14th to the 17th. Both Round Shoal and Great Rip were fished, but not the Chatham grounds.

At Round Shoal buoy a relatively small sample of cod was obtained (275 fish), but it was sufficient to show that the same stock of cod present throughout the spring and summer was still there. (Fig. 20, No. 3.) Although October begins the western migration of cod from Nantucket Shoals and from grounds to the north and east, the lengths of the Round Shoal October cod do not suggest that there had been even a small influx of foreign cod. We did, however, find cod somewhat less plentiful on the Round Shoal grounds in the fall than during the spring and summer of 1927, so that a small part of the stock of fish could have already started westward without such a fact being registered in the graph. Again, the dominant length of the *D* cod remained at 21 inches, as it did during the period from June to late August, and it would appear from this that these cod grew but little throughout the summer.

At Great Rip we had a somewhat different situation in October, 1927. (Fig. 22, No. 3.) The *D* cod were still dominant at 23 to 25 inches, compared to 22 to 24 inches in June, 1927, but a new school with individuals greater than 26 inches long arrived on the grounds some time between the middle of June and October. Apparently this school was not very large, for it was not found between Round Shoal and Rose and Crown buoys. (Fig. 20, No. 3) It is likely that these larger fish were on their way westward and that they originated from a region other than Nantucket Shoals or, at any rate, from a part of the shoals where no tagging had been done.

Summing up the year 1927, we find that the same school of cod was distributed over all the tagging grounds throughout the spring, summer, and fall. These fish, designated as the *D* cod, were first noted on Nantucket Shoals in August, 1925 (fig. 17, No. 3), when they were around 14 inches long and formed only a relatively small part of the total stock of cod. In October, 1925, the *D* cod were just a little more prominent than in August. (Fig. 17, No. 4.) They were next found on the one cruise made in 1926 in September at both Great Rip and Round Shoal, where they formed the dominant school. At Great Rip in 1926 the individuals of the *D* school centered around 20 inches long and at Round Shoal around 18 inches. Throughout 1927 this *D* school was even more dominant than in 1926 and monopolized all the tagging grounds at all times, excepting at Great Rip, where a small school of large fish appeared in the fall.

A smaller percentage of Nantucket cod was recaptured to the westward during the winter of 1926–27 than during any of the other winters since 1923, so it is apparent that a large part of the *D* cod remained stationary on Nantucket Shoals throughout 1926 and 1927, neither emigrating during those summers nor migrating westward during the winter. As the *C* cod disappeared from the shoals during the winter of 1926–27 most of them probably migrated westward the fall of 1926, but a large part of the catch made in the Rhode Island-North Carolina region that winter evidently consisted of fish which migrated from parts of Nantucket Shoals, where no tagging had been done, as well as from the regions to the north and east of Nantucket. If many of the cod came from the latter locality they did not pass over the Nantucket tagging grounds when we were fishing there in October, 1926, nor were they present on the shoals during 1927, or they would have been detected then in the length frequencies of the fish caught. Such of these fish as survived the winter in the Rhode Island-North Carolina region returned eastward in the spring and evidently did not stop on Nantucket Shoals.

LENGTHS OF NANTUCKET COD IN 1928

Two tagging cruises were made to Nantucket Shoals during 1928—the first from July 14 to 21 and the second from October 24 to 29.

It was found on the July cruise that the *D* cod still formed the dominant school on the Round Shoal buoy grounds (fig. 23, No. 1) as they did throughout 1926 and 1927. The very sharp peak made by the *D* cod in October, 1927 (fig. 20, No. 3), had been considerably reduced by July, 1928, due perhaps to the increase in age of the fish, which resulted in a greater variability in the lengths and to the appearance of a school of smaller cod, *E*. These *E* cod, centering around 18 inches long, migrated to the Round Shoal buoy grounds some time between October, 1927, and July, 1928. It will be noted that these fish appeared in very much the same way as the *B* cod which eventually supplanted the *A* (fig. 15, No. 1), the *C* cod which supplanted the *B* (fig. 16, No. 3), and the *D* cod which replaced the *C* (fig. 17, Nos. 3 and 4). It is possible, therefore, that while the *E* cod formed a relatively small part of the stock of fish in July, 1928, they might become the dominant group on Nantucket Shoals in 1929 and perhaps in 1930.

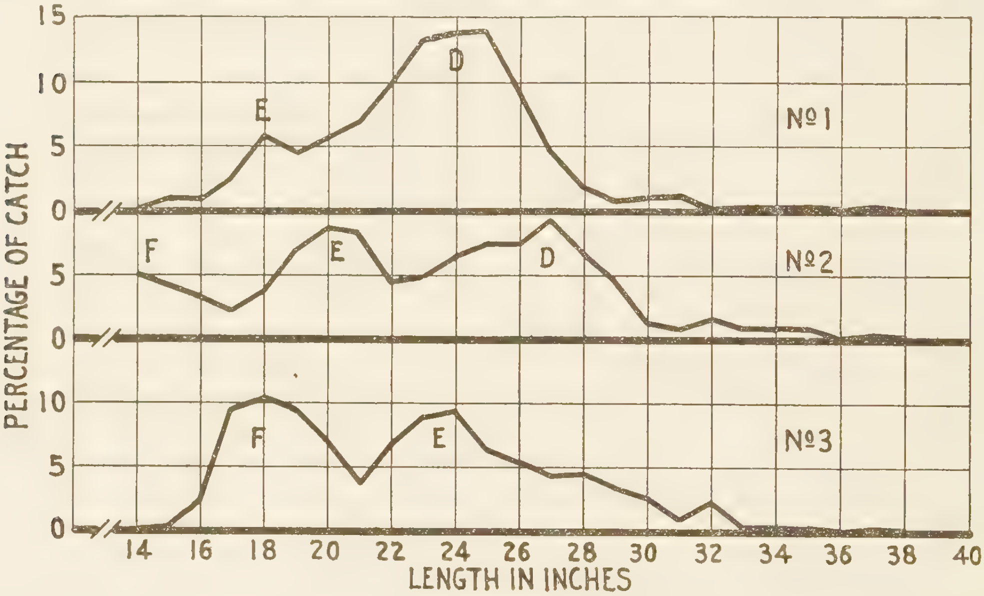

FIGURE 23.—*No. 1*=length-frequency distribution of 694 cod caught at Round Shoal buoy July 14–21, 1928. *No. 2*=length-frequency distribution of 304 cod caught from Round Shoal buoy to Great Rip buoy October 24–29, 1928. *No. 3*=length-frequency distribution of 624 cod caught from Round Shoal buoy to Rose and Crown buoy June 10–14, 1929

At Great Rip in July unfavorable weather conditions interfered with operations, with the result that only a few hours' fishing was done there and but 54 cod caught. The lengths of these are not shown graphically, but 7 fish, or 13 per cent of the catch, belonged to the 19-inch size and were possibly *E* cod; and 28 fish, or 52 per cent, belonged to sizes ranging from 23 to 27 inches, suggesting that if a large enough sample had been obtained the *D* cod, which were mostly 23 to 25 inches long at Great Rip in October, 1927, would be found still inhabiting this region.

Out of a total of 748 cod caught at Round Shoal and Great Rip only 4 fish were less than 15 inches long and only 8 fish were more than 31 inches long, so that the number of fish above and below these sizes present on the tagging grounds was negligible.

On the cruise made to Nantucket Shoals October 24 to 29, 1928, fewer cod were found than at any other time since the beginning of this investigation (p. 44). The *Albatross II* was shifted no less than forty times within the area bounded by Round Shoal buoy, Great Rip buoy, and the Chatham grounds in an attempt to find fish, but only 304 cod were caught. The lengths of these fish are given in Figure 23, No. 2. Because of the small catch of cod and the necessity of combining the several tagging grounds on Nantucket Shoals in order to show graphically an adequate sample, only a general comparison can be made between the October fish and those caught at Round Shoal buoy the previous July.

The *E* and the *D* cod were still present in October, although the gain of about 2 inches in length registered by each of these groups appears to be somewhat greater than we might have expected, judging by previous records, as, for example, the very slight gain in length made by the *D* cod from June to October, 1927. As to the status of the 14-inch cod in October, 1928, they may have just attained a size large enough to take a baited hook or they may have migrated from elsewhere. Their origin is discussed on page 92. Aside from the smallest fish which were caught in October, the length frequencies show that very much the same stock of cod was present then as in July, and that, therefore, few cod from other regions migrated to the tagging grounds on Nantucket Shoals during the interim.

LENGTHS OF NANTUCKET SHOALS COD IN 1929

By the summer of 1929 the *D* cod which were so abundant in July, 1928, and which appeared to be well represented in October, 1928, had disappeared from Nantucket Shoals. (Fig. 23.) It is likely that it was these fish which made up a large part of the migrating body which went westward the fall of 1928, and as a result many of them were caught by the fishery, and the survivors which returned in the spring of 1929 were too scattered to show up in the frequency distribution on the tagging grounds between Round Shoal and Rose and Crown buoys.

The prediction made in 1928 that the *E* cod might become the dominant body in 1929, and possibly in 1930, apparently will not materialize, for in June, 1929, they formed about the same proportion of the stock of fish as they did the previous October, and in all probability they will pass out of the picture over the winter of 1929–30. It seems, therefore, that the *E* cod were a much smaller school than were the *D* fish which were the dominant body of cod on the shoals throughout 1926, 1927, and 1928.

The status of the cod centering around 17 to 19 inches and designated as *F* fish, which were present in June, 1929, is rather uncertain, but, judging from the results obtained during the previous years, they were most likely derived from the fish around 14 inches long present in October, 1928. Whether these *F* fish are present on Nantucket shoals in 1930 or later depends partly on how abundant and widespread they are and on how many of them migrate into the Rhode Island-North Carolina region the fall of 1929. As at least one school of cod is present on the shoals each year, it would seem that the *F* fish would be the most likely inhabitants in 1930.

On the Great Rip tagging grounds only 80 cod were caught in June, 1929, and are not shown graphically. It was found, however, that 21 of these, or about one-fourth the total, were 18 to 20 inches long, or in the category of the *F* Round Shoal-

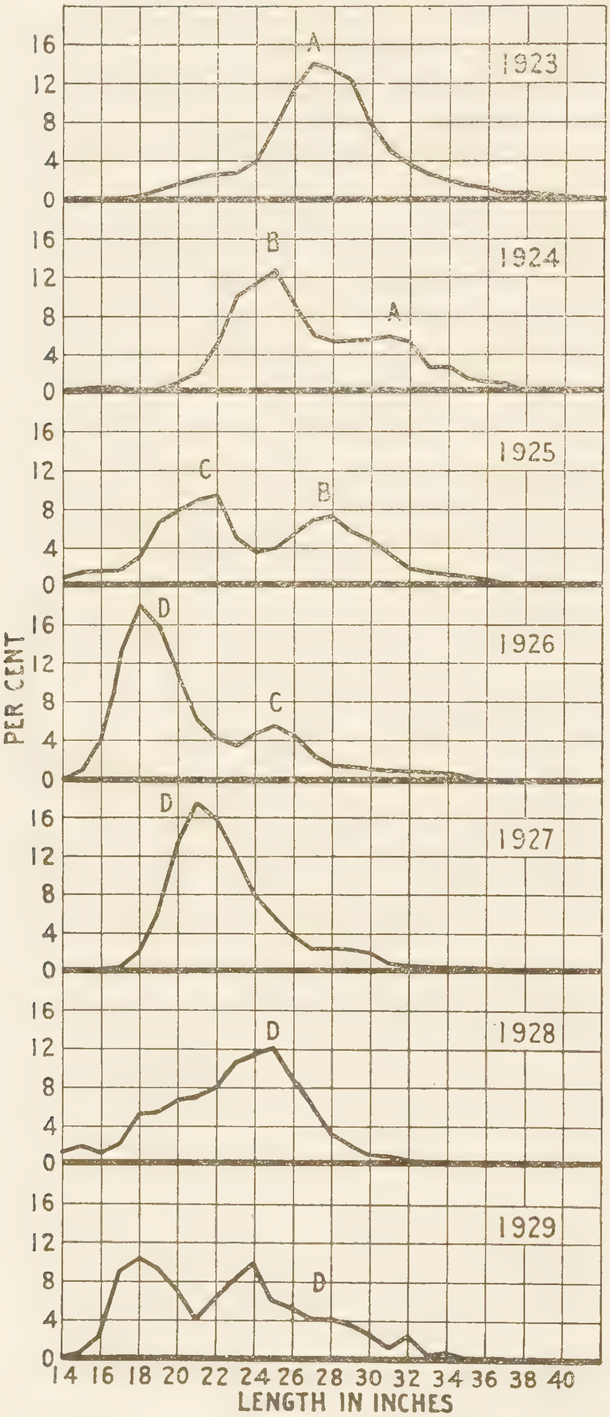

FIGURE 24.—Length-frequency distributions, based on Table 28, of all cod caught on Nantucket Shoals from 1923 to 1929 by the *Halcyon* and the *Albatross II*. The symbols A to D refer to the same stocks of fish as given on Figures 15 to 23

Rose and Crown fish. Here, again, as in almost all previous cases, the Great Rip fish averaged slightly larger than the Round Shoal-Rose and Crown fish, which is added proof that fish living in this region grow a little faster than those living 10 to 20 miles farther northward, around the other two buoys.

We found further evidence in June, 1929, that large cod do not remain on Nantucket shoals for an extended period. At that time scarcely 1 per cent of the catch made by the *Albatross II* consisted of fish more than 34 inches long.

It was found, therefore, that during 1929, up to June, the *D* cod which were first noted in August, 1925, and some of which were still present the fall of 1928, had virtually disappeared; that the *E* cod, which appeared in July, 1928, were on the wane; and that the *F* fish of October, 1928, had become the dominant school of cod on the tagging grounds.

The length distributions of all the cod caught on Nantucket Shoals from 1923 to 1929 by the *Halcyon* and the *Albatross II* are shown in Figure 24 and might be summarized as follows:

1. Length frequencies have shown that the cod population on Nantucket Shoals is rather stable from spring to fall of most years and that usually relatively few cod migrate to or from the shoals throughout the summer.

2. In the fall of some years a marked temporary change in the length-frequency distribution shows that "foreign" cod pass by

Nantucket Shoals at this time, evidently on their way westward, while in the fall of other years virtually no "foreign" cod could be recognized on the Nantucket tagging grounds at the time we fished there.

3. The relationship of lengths (corroborated by tagging experiments) from year to year indicates that (*a*) an appreciable part of the Nantucket Shoals cod do not migrate westward over the winter, but remain stationary; (*b*) many of those Nantucket cod which do migrate westward and survive the winter return to Nantucket Shoals the next spring; (*c*) cod which migrate from such banks as Georges or Stellwagen into the Rhode Island-North Carolina region pass by Nantucket Shoals, and in the spring such "foreign" fish return to the eastward and do not tarry on the shoals, else at that time they would have revealed themselves by their size distribution.

4. Six distinct bodies of cod were found on Nantucket Shoals during our tagging operations from 1923 to 1929. One of these was present when we began fishing the spring of 1923; one appeared in the fall of each of the years 1923, 1924, and 1925; and two the fall of 1928. By the year following their first appearance each of these schools in turn formed a dominating size and age group.

5. The dominant sizes of five schools of cod when they first appeared in the length-frequency distribution were 21 to 23 inches, 15 to 17 inches, 14 to 16 inches, 17 to 19 inches, and 14 inches. These appeared, respectively, during the years 1923, 1924, 1925, and the last two during 1928.

6. Cod below 16 inches were scarce in our catches, due perhaps partly to the selectiveness of our hook-and-line gear, but the sudden appearance of cod as large as 17 to 19 inches and 21 to 23 inches, as just noted, indicates that such fish migrated from some other region rather than that they grew up on the shoals from the fry or yearling stage.

7. The smaller cod on Nantucket Shoals are not as migratory as the larger fish. Cod less than about 24 inches long are apt to remain there for an extended period, while fish about 28 to 30 inches long and larger tend to move into deeper water. The scarcity of large cod on the shoals is, therefore, not due entirely to depletions caused by the fishery.

8. Length frequencies have shown that fish belonging to the same group may average 1 or 2 inches longer on the southern part of Nantucket Shoals than on the northern, due probably to faster growth.

POSSIBLE CAUSES FOR THE MIGRATIONS MADE BY SOUTHERN NEW ENGLAND COD

What is known of other species of fish suggests that spawning, food, and temperature are the most probable stimuli which induce cod to migrate. Unquestionably all cod, taken as a whole on both sides of the Atlantic, do not carry out the same migratory schedule. In fact, the cod is a poor example of a migratory fish, for all tagging experiments that have been made in the past have shown that a large part of the cod living on a ground one season will be found there a year later and sometimes longer. Obviously only mature fish carry out a spawning migration, but whether or not cod migrate in order to spawn depends on local circumstances such as depth, as it is believed that to deposit their eggs they usually seek water shoaler than 35 fathoms.

Many fishes along our shores are present during only part of the year, making their appearance and disappearance regularly at certain seasons. Apparently temperature has either a direct or an indirect influence on such migrations. The cod, taken by and large, is not one of the "disappearing" fish, for on most of the grounds which it frequents it is found throughout the year. Whether or not cod shift ground to avoid extremes of temperature seems to depend somewhat on the age of the fish. For example, Schmidt (1907, p. 23) found that cod during their first few years of life remained localized in the cold water of the north and east coasts of Iceland, but that as they approached maturity and the urge to spawn they migrated to a warmer region on the south coast, probably because they became more sensitive to external conditions.

The extremes of temperature in which cod have been found range from around 0° to about 15° C. and occasionally as high as 16° to 17° C., although in any given region the range ordinarily would be smaller than this. Bodies of cod living in very cold water, therefore, might respond differently to a given temperature than cod living in moderately cold water. Huntsman (1925), writing of the cod around the mouth of the Gulf of St. Lawrence, states that "For them 50° F. is rather too warm and 32° F. too cold, and possibly 40° to 45° F. would be considered just right. They

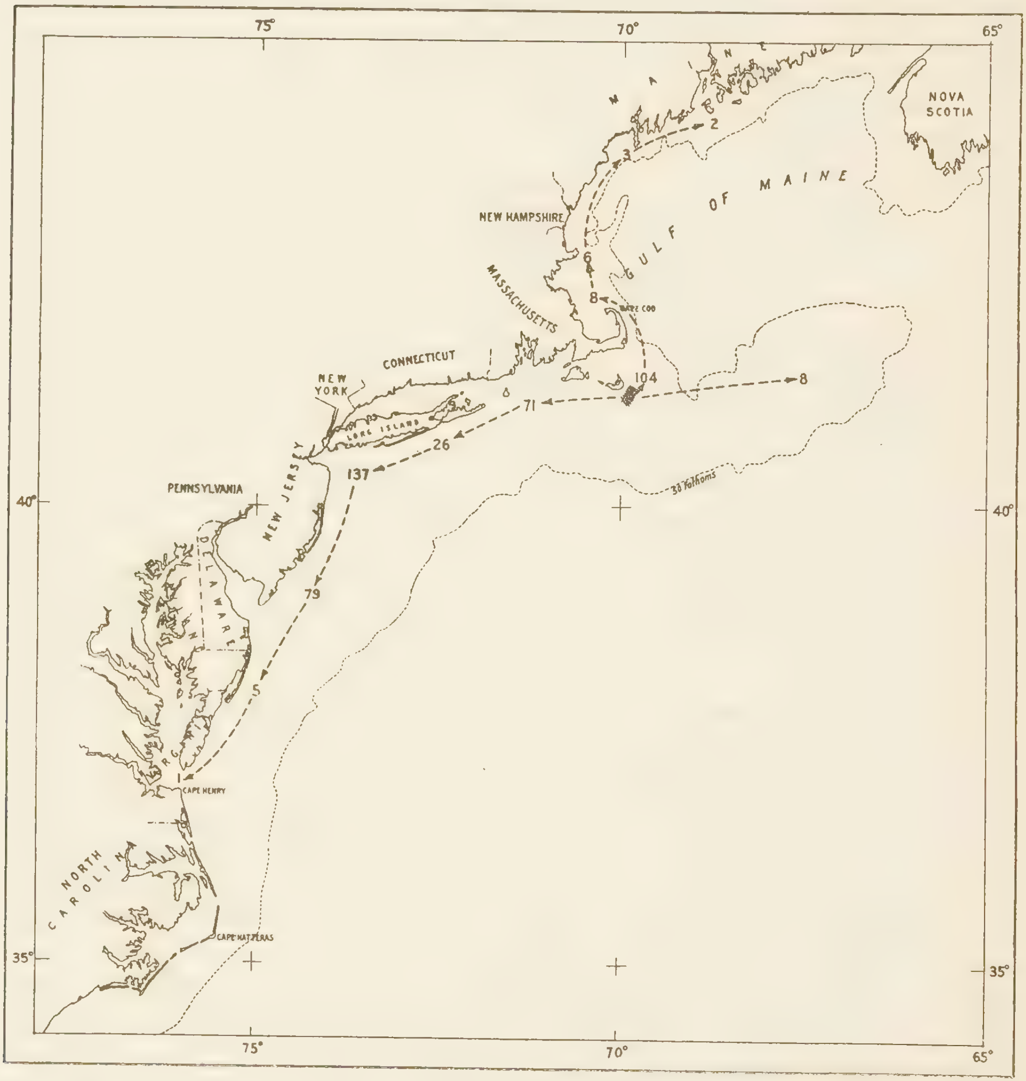
75°
70°
65°
MAINE
NOVA SCOTIA
2
3
GULF OF MAINE
NEW HAMPSHIRE
6
8
CAPE COD
MASSACHUSETTS
CONNECTICUT
NEW YORK
LONG ISLAND
104
8
71
26
137
PENNSYLVANIA
40°
NEW JERSEY
DELAWARE
30 fathoms
79
5
CAPE HENRY
NORTH CAROLINA
CAPE HATTERAS
35°

FIGURE 25.—Routes taken by cod which migrate or emigrate from Nantucket Shoals. The figures indicate the number of recaptures reported from each general locality from 1923 to October, 1929. Total number of cod tagged on Nantucket Shoals, 22,228

leave northern waters on the approach of winter and pass that season in the ocean south of Newfoundland." In the Barentz Sea, where the annual temperature range on bottom is from about 0° to about 5°, Averinzev (1928, p. 117–126) found that cod and haddock appeared to change ground in order to keep in water of 3° to 4°, shunning 0°, although even in the latter temperature some cod were caught. However, these latter observations do not prove that the cod shifted ground as a result of a direct thermal stimulus, for it may have been that in the warmer water a more abundant food supply was present and attracted the cod thither.

The nature and extent of the cod's migrations depend largely on the geography of its environment, in conjunction with the other factors just mentioned. For instance, the maturing Icelandic cod which migrate from the north to the south coasts might very well continue farther if it were not for the deep water (400 to 600 meters) between there and the Faroes. In the same way the migrations of the Faroes fish are restricted because this bank is surrounded by water deeper than that ordinarily frequented by the cod. The long migrations of European cod, from Lofoton to the Finmark coast (Hjort, 1914, fig. 69), and from Finmark back to Lofoton and even southward (ibid., fig. 134), and of American cod from New England to as far as North Carolina, are allowed by the fact that there are no depth barriers to stop them, and the temperature, at certain seasons at least, is favorable all along the route. But passive factors such as these can not be supposed to provide a stimulus for a regular seasonal migration.

Nantucket Shoals cod make two distinct migrations—one into the Rhode Island-North Carolina region each winter and the other, during certain summers, into the Chatham-South Channel region near by. (Fig. 25.) As these two migrations differ in route, season, and regularity of performance, the possible causes for them are discussed separately.

There are, in addition to the fish just mentioned, which travel over a definite migratory route, other cod which straggle into the region north of Cape Cod. Why so few cod go eastward and north from southern Massachusetts is not known. Apparently these southern grounds afford a very favorable environment for the cod, so that most of the fish which enter it remain there for an extended period. This could still be true, and yet there would be no danger of the cod overpopulating the grounds, for not only is a regular fishery carried on there most of the year, but in addition large numbers of them are caught during their sojourn on the wintering grounds to the westward.

THE WINTER MIGRATION

Spawning as a possible cause.—It might be considered significant that the spawning period of the cod off the New England coast coincides with the time when the migration to the westward of Nantucket Shoals takes place. But Nantucket Shoals itself is an important spawning ground, and it is not likely that cod from there would journey as far as 200 or 300 miles west and south to spawn in a region apparently unsuitable for them during the summer when so many other cod remain to spawn on the shoals, while others gather there for that purpose.

It might again be suggested that the cod which summer on Nantucket Shoals are the ones which go west for the winter, and that the fish which spawn in winter on the shoals come from farther east. But tag records have shown that most of the few fish tagged on Stellwagen, Georges Bank, and off Nova Scotia, and which are known to have migrated toward Nantucket Shoals, passed on, for they were recaptured between Block Island, R. I., and Rockaway, N. Y. Furthermore, a few of the cod tagged in summer on Nantucket Shoals have been recaptured there in winter, and many marked fish retaken almost on the same spot the year following strengthen the suspicion that such cod did not migrate to Rhode Island or westward over the winter.

Although spawning apparently does not prompt this westward migration, neither did it deter it, because cod are known to spawn all along the migratory route, at least as far as southern New Jersey, as appears from the following lines of evidence:

Off eastern Long Island Fred P. Bradford states that cod with spawn are taken throughout the winter and a few even as late as the first week in April.

On the Cholera Bank, off western Long Island, N. Y., out of 166 fish the *Albatross II* caught 34 males and 6 females from November 14 to 21, 1927, so ripe that the milt or eggs flowed from the vent when the fish were laid on the measuring board. Again, from November 8 to 24, 1928, there were 28 ripe males and 2 ripe females among the 134 cod that were caught.

For the region off southern New Jersey, Smith (1902, p. 208) records nearly ripe cod off Atlantic City. On the present investigation fishermen in southern New Jersey reported that each winter many cod were taken "with large milts and roes." The majority of these spawning cod are taken in November and December, while a few are found throughout the winter, and a small run occurs in late March and early April, at the end of the season. During our tagging operations 13 ripe males and 1 female were noted among 93 cod caught off Atlantic City December 12 to 19, 1928, and 5 ripe males were among 133 cod caught there in March and April, 1928. No record was kept by the fishermen who tagged cod for us off Cape May the winter of 1928–29, but they reported that ripe fish were caught from time to time.

During March and April, 1929, and in May, 1927, O. E. Sette reports that the *Albatross II* caught cod larvæ to as far south as the region between Delaware Bay and North Carolina, and others were caught in this region on cruises made in February, March, and April, 1930.

Although in some years almost all the cod taken to the west of Rhode Island are adult (over about 20 inches long), sometimes, as in the fall of 1926, many fish as small as 16 inches are caught. The *Albatross II* on a chance otter-trawl haul made February 28, 1929, off northern New Jersey caught 6 cod which were of the following total lengths: 14, 15¾, 16, 17¾, and 23½ inches. Some of these were males and some females. All were immature, except the largest one. The presence, at times, of these immature cod west of Rhode Island offers further evidence that this is not fundamentally a spawning migration, even though cod may spawn off New Jersey just as freely as on Nantucket Shoals.

Food.—The same foods that are the staple diet of the cod on Nantucket Shoals—largely crabs (Cancer, Hyas, Libinia), shrimps, worms, small bottom fishes, etc.—are plentiful on all suitable bottoms along the western migratory route.

Crabs, which form the bulk of the cod's food off southern Massachusetts, are present there throughout the year, so it is not because of the seasonal scarcity of them that cod go west. In the New York-New Jersey region rock crabs (Cancer) are plentiful the year around; thus, the return from New Jersey back to Nantucket Shoals in the spring is not induced by a local exhaustion of this food. It is obvious that other bottom forms such as worms, small mollusks, shrimps, etc., can have no influence on the migration of Nantucket cod, because they are always present all along our coast.

Cod will eat any fish that they can catch, especially the small silvery species that travel in dense schools, and so are easily caught. The most important of these are capelin (Mallotus), herring (Clupea), and sand eels (Ammodytes).

Capelin, of course, are restricted to arctic and subarctic regions and hardly extend south to Maine along our coast. But it is of interest to note that in the far north cod pursue capelin for long distances, feeding voraciously upon them. This occurs regularly off Labrador and Greenland and also off the Finmark and Murman coasts, as noted by Hjort (1914, p. 113).

Cod often feed on herring, both small and large, and there is evidence that they pursue this food, at least for short distances. But Clupea are not particularly plentiful off the southern coast of Cape Cod, while to the westward of Montauk Point they are relatively scarce, and hence could hardly induce the cod's migration into that region.

The sand eel (Ammodytes) is the only one of the really important fish foods of the cod that is found in abundance on Nantucket Shoals and on the wintering grounds to the westward. But although the season when sand eels are abundant alongshore, west of Massachusetts, coincides with the season when cod are present there, we have no proof that cod are induced westward in order to feed upon them. This is made apparent by the fact that although Ammodytes is important to the cod to the westward of the shoals, as well as throughout most of the cod's range, the food that must be depended upon there from day to day is the same sort as on all suitable bottoms off the New England coast, namely, crabs, shrimps, mollusks, brittle stars, worms, and occasional fishes of various species. Thus there is no basis for explaining this as a feeding migration.

Competition for food between the cod and other fishes on Nantucket Shoals and the wintering ground to the westward.—It would seem that ordinarily cod were given relatively little serious competition for their food supply by other species of fish, particularly on Nantucket Shoals, for in this region only the haddock and the pollock, taken both from the point of size and of abundance, can be considered at all of importance in this respect. But as haddock eat chiefly the smaller crustaceans and mollusks, of a size generally disdained by the cod, it seems obvious that neither fish competes very seriously for the other's food supply. The same can be said with respect to the pollock, for the latter feeds largely on squid and fish and, on Nantucket Shoals at least, eats very sparingly of the larger crustaceans which make up the bulk of the cod's food.

To the westward of Nantucket Shoals, excepting possibly the Rhode Island region, neither the haddock nor the pollock are sufficiently plentiful to affect the cod's food supply. But in this westward region other species occur abundantly that are rarely found on the shoals, including the sea bass (Centropristes), the tautog (Tautoga) and the summer flounder (Paralichthys). It so happens that throughout the summer these species occupy the same rocky bottoms, wrecks, etc., that are inhabited by some of the cod during the winter, but this alternative occupation of the grounds goes on year after year, so it is apparent that neither body of fish exhausts the other's food supply. Even if the summer fish did reduce considerably the food supply on the rough bottoms, it remains that much the larger part of the schools of cod distribute themselves over sandy, shelly, and gravelly bottoms whose area far exceeds that of the rocky bottom and whose food supply is scarcely disturbed by the summer species just mentioned. It appears evident, therefore, that competition for food between the cod of Nantucket Shoals and other species of fish has little or nothing to do with causing them to migrate westward from the shoals in the fall or in limiting their stay on the wintering grounds.

Enemies.—Enemies in the form of other fishes do not drive cod from Nantucket Shoals. Its only important and widespread enemy there is the dogfish (Squalus), but although the dogfish migrate southward in great hordes from the Gulf of Maine to at least the Chesapeake Capes, the first of them appear off New York or New Jersey about a week before the cod, not after them or with them, and they pass on and are not seen again, except for a straggler, anywhere on the cod grounds from Nantucket Shoals to Delaware until the following April when the water has warmed to about 5.5° C. (42° F.). Although both dogfish and cod may migrate westward from Nantucket Shoals at the same time during part of November, cod continue to leave the shoals until well into December, long after the dogfish have passed.

Salinity.—No exhaustive attempt has been made here to correlate the presence and abundance of cod with the salinity of the water. On grounds where cod are present the year around the following salinity data have been taken from Bigelow (1927, p. 815–19): Below 150 meters (about 80 fathoms) the salinity fluctuates only about 0.5 per mille throughout the year and ranges around 33.7 to 34.2. At depths of 100 to 150 meters (about 55 to 80 fathoms), in the coastal zone between Cape Cod and Cape Sable, the variation runs from about 32.38 to 34.11, according to depth, locality, and date. In the 40 to 100 meter zone (about 22 to 55 fathoms), which includes most of the cod grounds off our coast, the range in salinity throughout the year is about 31.8 to 33.2 per mille.

On Nantucket Shoals there appears to be very little fluctuation in the salinity during the summer, autumn, and winter, when, at 20 to 40 meters (11 to 22 fathoms), it probably is around 32 to 32.5 per mille, while in the spring it is only slightly lower.

An indication that cod are not usually influenced to migrate by ordinary changes in salinity may be had from our tagging experiments in the immediate shore waters of Maine which showed that many of the cod remained localized from one year to the next, although the water freshens there in the spring more than it does offshore. In line with this, Needler (1929, p. 9) found that in the Gulf of St. Lawrence cod are often caught in a salinity around 30 per mille, which is fresher than that found on bottom on the banks off New England.

Therefore there is no reason to believe that fluctuations in salinity cause cod living along the New England coast, particularly those on Nantucket Shoals, to make extensive migrations.

Temperature.—One of the striking things about the migration of cod from southern Massachusetts into the Rhode Island-North Carolina region is that it begins each year in October. For this reason it would appear that a falling water temperature was the stimulus which sent the fish on their journey.

As Nantucket Shoals is the most southerly year-around cod ground along our coast, we might reasonably expect that seasonal differences in water temperature would have more influence on the migrations of the cod living there than would be the case in an intermediate region where the extremes of temperature would not be as great. However, an examination of the data for the Nantucket-Delaware region is not so reassuring.

Temperatures taken on Nantucket Shoals are given in Table 31. In general it can be said that the water there reaches a maximum of about 11° to 15.5° C. (52°

to 60° F.) in the late summer, the degree depending on whether it is a cold or a warm year. The minimum temperature in late winter probably is somewhere between 2° and 3° C. (35.6° to 37.4° F.), for on February 24, 1929, we found it to be 1.4° C. (34.5° F.) on the surface and 2.6° C. (36.7° F.) on the bottom in 11 fathoms off Round Shoal buoy where so many of our cod were tagged on the shoals from April to October.

We naturally examine with interest the temperatures west of longitude 70° W., particularly those of late summer, in the hope of finding some explanation as to why cod go there in the fall to spend the winter but leave again in the spring. The temperatures given in Table 30 were selected to cover (*a*) the period when the first cod migrate westward from Nantucket Shoals, (*b*) the period of maximum migration, (*c*) midwinter, (*d*) the period in the spring when the last of the cod are believed to leave their southern wintering grounds, and (*e*) the period in summer when maximum temperatures obtain and when cod have seldom been found west of Rhode Island. The temperatures which are listed were taken on or within a few meters of the bottom and each represents a different station. Those recorded prior to 1926 were taken from Bigelow (1915, 1917, 1922, 1927) and those after were obtained by the *Halcyon* and the *Albatross II* on tagging and hydrographic cruises.

TABLE 30.—*Bottom water temperatures from west of Nantucket Shoals*

[All positions listed are true positions. The letters before the station numbers are to be interpreted as follows: A = *Albatross II;* G = *Grampus;* and H = *Halcyon*]

Reference No.	Station	Date	Position	Locality	Depth		Temperature	
					Meters	Fathoms	° C.	° F.
			° ′	*Off Marthas Vineyard and Rhode Island*				
1	A 20261	May 25, 1927	41 06 N. 70 47 W.	10 miles S. by E. from No Mans Land	30	16	7.7	45.8
2	G 10357	July 26, 1916	41 11 N. 70 44 W.	5 miles SE. from No Mans Land	25	13	14.3	57.7
3	G 10356	do	40 57 N. 70 18 W.	28 miles SE. from No Mans Land	30	16	12.1	53.8
4	G 10355	July 25, 1916	40 43 N. 69 53 W.	57 miles SE. from No Mans Land	30	16	11.0	51.8
5	G 10354	do	40 26 N. 69 24 W.	80 miles SE. from No Mans Land	70	38	6.1	43.0
6		Aug. 2, 1926		1 mile NW. from Gay Head, Marthas Vineyard	13	7	16.1	61.0
7		do		2½ miles SW. from Gay Head, Marthas Vineyard	27	15	16.0	60.8
8	G 10112	Aug. 22, 1913	40 17 N. 70 57 W.	57 miles S. by W. from No Mans Land	110	60	15.4	59.7
9	G 10263	Aug. 27, 1914	41 12 N. 70 57 W.	6 miles SW. from No Mans Land	17	9	13.3	55.9
10	G 10258	Aug. 25, 1914	41 03 N. 70 51 W.	13 miles S. from No Mans Land	30	16	12.1	53.8
11	G 10259	do	40 34 N. 70 46 W.	41 miles S. from No Mans Land	55	30	9.7	49.5
12	G 10262	Aug. 26, 1914	40 02 N. 70 26 W.	80 miles S from east end of Marthas Vineyard	180	98	10.3	50.5
13	G 10260	do	40 03 N. 70 41 W.	80 miles S. from west end of Marthas Vineyard	140	76	11.4	52.2
14	G 10331	Oct. 22, 1915	41 19 N. 70 55 W.	4 miles E. from west end of Marthas Vineyard	30	16	14.5	58.0
15	G 10332	do	40 51 N. 70 55 W.	24 miles S. by W. from No Mans Land	50	28	13.1	55.1
16	G 10333	do	40 26 N. 70 56 W.	48 miles S. by W. from No Mans Land	80	44	11.9	53.4
17		Oct. 28, 1925	41 12 N. 70 51 W.	4 miles S. from No Mans Land	18	10	12.1	53.8
18		Oct. 27, 1925	41 18 N. 71 00 W.	8 miles E. from west end of Marthas Vineyard	33	18	11.7	53.0
19		do	41 11 N. 71 28 W.	6 miles E. from Block Island	22	12	11.7	53.0
20	G 10405	Nov. 10, 1916	41 17 N. 71 03 W.	10 miles E. from west end of Marthas Vineyard	30	16	12.5	54.4
21	G 10406	Nov. 11, 1916	40 37 N. 71 19 W.	34 miles S. from Block Island	60	32	10.0	50.0
22	G 10407	do	40 03 N. 71 43 W.	67 miles S. by W. from Block Island	90	49	7.7	45.8
23	G 10408	do	39 52 N. 71 47 W.	80 miles S. by W. from Block Island	180	98	10.3	50.5

TABLE 30.—*Bottom water temperatures from west of Nantucket Shoals*—Continued

[All positions listed are true positions. The letters before the station numbers are to be interpreted as follows: A = *Albatross II*; G = *Grampus*; and H = *Halcyon*]

Reference No.	Station	Date	Position	Locality	Depth		Temperature	
					Meters	Fathoms	° C.	° F.
			° ′	*Off Long Island, N. Y.*				
24		Feb. 21, 1925	40 21 N. 73 44 W.	21 miles SE. from Fort Wadsworth, N. Y	22	12	3.6	38.5
25	A 20403	Feb. 28, 1929	40 23 N. 73 52 W.	16 miles SE. by S. from Fort Wadsworth, N. Y	30	16	2.1	35.8
26	A 20402	do	40 04 N. 73 14 W.	49 miles SE. ½ E. from Fort Wadsworth, N. Y	45	24	4.4	39.9
27	A 20401	do	39 49 N. 72 58 W.	70 miles SE. from Fort Wadsworth, N. Y	70	38	6.9	44.4
28	A 20400	do	39 33 N. 72 33 W.	93 miles SE. from Fort Wadsworth, N. Y	80	44	7.5	45.5
29	A 20399	Feb. 27, 1929	39 23 N. 72 18 W.	110 miles SE. from Fort Wadsworth, N. Y	150	82	11.4	52.5
30	A 20232	May 19, 1927	40 20 N. 73 48 W.	20 miles SE. by S. from Fort Wadsworth, N. Y	45	24	4.7	40.5
31	A 20230	do	40 00 N. 73 20 W.	47 miles SE. from Fort Wadsworth. N. Y	50	28	5.2	41.4
32	A 20253	May 24, 1927	40 39 N. 72 34 W.	13 miles S. by W. from Shinnecock Light	30	16	5.0	41.0
33	G 10067	July 13, 1913	40 29 N. 73 46 W.	16 miles ESE. from Fort Wadsworth, N. Y	22	12	9.5	49.2
34	G 10362	Aug. 1, 1916	40 22 N. 73 38 W.	24 miles SE. by E. from Fort Wadsworth, N. Y	22	12	11.9	53.4
35	G 10363	do	40 13 N. 73 21 W.	40 miles SE. by E. from Fort Wadsworth, N. Y	30	16	8.1	46.6
36	G 10364	do	40 01 N. 72 56 W.	63 miles SE. by E. from Fort Wadsworth, N. Y	40	22	5.5	41.9
37	G 10365	Aug. 2, 1916	39 41 N. 72 39 W.	84 miles SE. ½ E. from Fort Wadsworth, N. Y	60	32	4.8	40.6
38	G 10366	do	39 40 N. 72 23 W.	95 miles SE. by E. from Fort Wadsworth, N. Y	90	49	5.8	42.4
39	G 10367	do	39 34 N. 72 01 W.	112 miles SE. by E. from Fort Wadsworth, N. Y	200	109	7.9	46.2
40	G 10396	Aug. 26, 1916	40 50 N. 72 07 W.	20 miles SW. by S. from Montauk Point	28	15	12.1	53.8
41	G 10395	do	40 32 N. 72 44 W.	24 miles E. by S. from Fire Island Light	35	19	9.0	48.4
42		Nov. 14, 1927	40 24 N. 73 37 W.	Cholera Bank	18	10	12.7	55.0
43		Nov. 15, 1927		do	18	10	12.5	54.4
44		Nov. 20, 1927		do	18	10	11.4	52.5
45		Nov. 21, 1927		do	18	10	10.8	51.4
46		Nov. 10, 1928		do	18	10	12.2	54.0
47		Nov. 15, 1928		do	18	10	12.1	53.7
48	A 20374	Nov. 13, 1928	40 36 N. 73 05 W.	7 miles ESE. from Fire Island Light	22	12	11.8	53.2
49	A 20375	do	40 16 N. 72 46 W.	30 miles ESE. from Fire Island Light	50	28	12.5	54.6
50	A 20376	do	39 51 N. 72 23 W.	60 miles ESE. from Fire Island Light	75	41	12.6	54.8
51	A 20377	do	39 37 N. 72 09 W.	79 miles ESE. from Fire Island Light	110	61	12.9	55.2
				Off New Jersey				
52	A 20304	Feb. 17, 1928	38 46 N. 74 38 W.	19 miles SE. by E. from Cape May Light	28	15	4.6	40.4
53	A 20305	do	38 24 N. 74 13 W.	48 miles SE. by E. from Cape May Light	47	25	8.8	47.8
54	A 20406	Mar. 3, 1929	38 42 N. 74 51 W.	16 miles SSE. from Cape May Light	15	8	3.3	37.9
55	A 20414	Mar. 4, 1929	38 30 N. 74 25 W.	37 miles SE. from Cape May Light	30	16	5.9	42.6
56	A 20415	do	38 20 N. 74 04 W.	56 miles SE. ½ E. from Cape May Light	45	24	7.2	45.0
57	A 20421	Apr. 14, 1929	38 41 N. 74 51 W.	15 miles S. by E. from Cape May Light	20	11	8.4	47.1
58	A 20438	Apr. 19, 1929	38 30 N. 74 15 W.	41 miles SE. from Cape May Light	30	16	6.8	44.2
59	A 20437	do	38 21 N. 74 03 W.	55 miles SE. from Cape May Light	60	32	10.1	50.2
60	A 20436	do	38 11 N. 73 43 W.	74 miles SE. from Cape May Light	170	93	11.4	52.2
61	A 20228	May 19, 1927	39 42 N. 72 47 W.	63 miles E. ½ S. from Barnegat Light	60	32	4.8	40.6
62	A 20235	May 20, 1927	39 20 N. 74 14 W.	10 miles E. by S. from Absecon Light	15	8	7.3	45.1
63	A 20237	do	39 11 N. 73 43 W.	35 miles ESE. from Absecon Light	40	22	5.8	42.4
64	A 20244	May 21, 1927	38 25 N. 74 16 W.	46 miles SE. from Cape May Light	40	22	6.5	43.7
65	G 10378	Aug. 11, 1916	38 48 N. 74 53 W.	9 miles SSE. from Cape May Light	14	8	21.0	69.9

TABLE 30.—*Bottom water temperatures from west of Nantucket Shoals*—Continued

[All positions listed are true positions. The letters before the station numbers are to be interpreted as follows: A=*Albatross II*; G=*Grampus*; and H=*Halcyon*]

Reference No.	Station	Date	Position	Locality	Depth		Temperature	
					Meters	Fathoms	° C.	° F.
			° ′	*Off New Jersey*—Continued				
66	G 10377	Aug. 10, 1916	38 54 N. 74 44 W.	11 miles E. by S. from Cape May Light	15	8	15. 8	60. 4
67	G 10379	Aug. 11, 1916	38 46 N. 74 35 W.	21 miles ESE. from Cape May Light	25	13	10. 9	51. 6
68	G 10375	Aug. 4, 1916	38 59 N. 74 08 W.	40 miles E. ½ N. from Cape May Light	40	22	6. 2	43. 1
69	G 10373	do	38 57 N. 73 35 W.	66 miles E. from Cape May Light	60	32	4. 5	40. 1
				South of New Jersey				
70	A 20407	Mar. 3, 1929	37 58 N. 75 02 W.	15 miles E. by N. from Assateague Light	15	8	3. 4	38. 1
71	A 20408	do	37 47 N. 74 40 W.	35 miles E. by S. from Assateague Light	40	22	5. 7	42. 2
72	A 20412	do	36 52 N. 75 20 W.	33 miles E. ¾ S. from Cape Henry Light	20	11	5. 0	41. 0
73	A 20411	do	36 49 N. 75 00 W.	49 miles E. ¾ S. from Cape Henry Light	30	16	7. 2	45. 0
74	A 20410	do	36 45 N. 74 36 W.	70 miles E. by S. from Cape Henry Light	180	98	9. 6	49. 4

Combined with what we know of this migration from other sources such as fishing, tagged fish, etc., these temperatures may be interpreted as follows:

When the first schools of cod migrate westward from Nantucket Shoals the latter half of October they leave behind them temperatures ranging from about 9° to 13° C. (48° to 55° F.) and enter a region that is somewhat warmer. In this region immediately to the westward of the shoals, off Marthas Vineyard and Rhode Island, temperatures the end of October (reference numbers 14 to 19, Table 30) in 18 to 80 meters out to about 50 miles from shore have ranged from 11.7° to 14.5° C. (53° to 58° F.). At this time the warmer water is found near shore, but many of the fish take this route, judging from the number that are caught within a few miles of shore late in October. By November, when the migration of cod is in full swing, the bottom temperatures are very much the same near shore as they are further off. Apparently the cooling of the water in the fall plays an important part in bringing about the migration, and even though the earliest fall migrants which leave in October enter a region slightly warmer than Nantucket Shoals at the time, the temperatures are not so high that they afford a barrier to a movement of cod farther to the westward. The fall migrants continue their journey, therefore, with the water becoming cooler and cooler as the season advances. They do not, however, keep pace with the temperature but migrate rapidly and appear off New Jersey only about a week after they pass Rhode Island.

In the late winter the shore waters west of Nantucket Shoals are much cooler than the offshore (reference numbers 21 to 29, 52 to 56, 70 to 74, Table 30), but after the cod reach there in the late fall most of them appear to remain localized until the spring. In general, the cod off the New Jersey coast may move offshore a few miles in the coldest part of the winter, probably to seek water that is 1° or 2° warmer, but there are times, as in January and February, 1928 and 1929, when good catches were made in the shoal water of Delaware Bay, that they remain inshore.

The cod leave their southern wintering grounds and return north and east to southern Massachusetts in the spring, after the water has started to warm. By the middle of April the majority of the cod have left the New York-New Jersey region, although at that time the water there is still much cooler than it is in the fall when the first cod arrive. A comparison of the Cholera Bank temperatures obtained in November with those taken off Cape May in mid-April will illustrate this (reference numbers 42 to 47 and 57 and 58). A further example is furnished by our results off Atlantic City, N. J., in 1928, when on April 1 it was 4° C. (39° F.) in 7 fathoms where cod were being caught and only 5.5° C. (42° F.) in the same place on April 13, by which time most of the cod had departed (as noted by the almost daily catches of the fishermen).

Even in May the water is still comparatively cool along the New Jersey shore, for during the middle of that month temperatures of 4.7° to 7.3° C. (40.5° to 45.1° F.) were found off the coast about 10 to 60 miles, while off Long Island, late in the month, a reading of 5° C. (41° F.) was obtained. Further eastward, in the vicinity of No Mans Land, the temperature in 16 fathoms taken late in the month was 7.7° C. (45.8° F.) (reference numbers 1, 30 to 32, 61 to 64, Table 30).

In all these cases the water temperature was well below the maximum which obtains on Nantucket Shoals and on many of the cod grounds off New England during the summer, so it is apparent that cod leave the region west of Rhode Island in the spring at least two months before the bottom water approaches the warmth that exists on their summering grounds on Nantucket Shoals.

During the summer, although there are virtually no cod caught west of Rhode Island, there are places which are presumably good cod ground where the temperature is as low and even lower than that on Nantucket Shoals. For instance, in the region 40 to 112 miles southeast by east from New York City (reference numbers 35 to 39) and 40 to 66 miles east of Cape May Light N. J. (reference numbers 68 and 69) temperatures ranging from 4.5° to 8.1° C. (40.1° to 46.6° F.) prevailed in August, 1916. The fact remains, however, that during the summer a large proportion of the best cod ground to the westward of Nantucket Shoals is covered by water, the temperature of which approaches or exceeds the maximum ordinarily tolerated by cod.

Neither the spawning instinct, the availability of food, changes in salinity, nor the presence of enemies appear, therefore, to be the cause of the annual migration of cod from southern Massachusetts into the Rhode Island-North Carolina region. Our present knowledge indicates that ordinarily cod tend to spread and occupy all suitable grounds unless prevented by depth or temperature barriers. As no depth barrier exists between Nantucket Shoals and the grounds to the westward, it would seem that temperature is the more direct cause, particularly as the migration is seasonal and the departure of cod from the shoals begins each fall when the water commences to cool. This assumption does not cover the return migration in the spring quite as well, because the grounds are vacated well in advance of temperatures high enough to constitute a barrier, as judged by the degree of warmth tolerated by cod on Nantucket Shoals in the summer. Nor does it explain why there is not an extensive spread of Nantucket Shoals cod to the north and east.

THE SUMMER MIGRATION

Spawning.—A spawning immigration, bringing foreign cod to the Chatham-South Channel region during the winter, may explain why the commercial catch holds up so well at that season. But this can not explain the summer movement of cod thither from Nantucket Shoals, because spawning in any amount is confined to the autumn, winter, and early spring. And we have no evidence from recaptures of any migration of cod eastward or northward from Nantucket Shoals during the spawning season.

Food.—Except in cases where cod could be observed following bait, such as sand eels (Ammodytes) or young herring (Clupea), it is difficult to ascertain what effect regional or seasonal variations in their food supply may have on their migrations. It has been observed that the bulk of the cod's food on Nantucket Shoals and on the Chatham grounds consists of large crustaceans. No cod stomachs have been examined in South Channel, but, being primarily a haddock ground, we can reasonably assume that the food supply as a whole is less attractive to the cod there than on the Chatham grounds or Nantucket Shoals. Two hauls with a fine-meshed shrimp trawl made in South Channel by the *Albatross II* on June 13, 1929, caught very little cod food such as crabs, medium-sized mollusks, worms, etc., but considerably more sampling must be done before a good picture of the food supply and bottom in the channel can be obtained.

If it should be proven that the food on the Chatham grounds is more attractive to the cod than the food in South Channel, it might explain why the former locality has yielded a greater portion of tagged Nantucket cod than has the channel region. But it would not necessarily prove that Nantucket cod migrate to the Chatham grounds primarily in search of better feeding grounds. On the contrary, nearly all the cod stomachs examined on Nantucket Shoals held a large amount of food, or at least as much as the stomachs of fish caught on various other banks, and nearly all the fish caught by us were fat and healthy. Equally, if food were scarce on the Chatham grounds few fish would live there and the region would have yielded a much smaller number of tagged Nantucket cod than was actually the case. So while it is apparent that the Chatham grounds ranks about the same as Nantucket Shoals in having sufficient cod food for holding bodies of fish the year around, yet there is no basis for believing that the food supply affords the chief stimulus for an intermigration between the two grounds.

Temperature.—There is no cod ground off our coast that has the peculiar temperature variations that obtain to the southeastward of Cape Cod, for there, on Nantucket Shoals, a close similarity exists between the surface and bottom temperatures, due to the tidal currents sweeping over its uneven bottom contour and thus stirring up the water, while, in contrast to this, the waters in the Chatham-South Channel region are stratified as to temperature, except for very brief periods in the spring and the fall. Temperature, therefore, appears to offer a hopeful field of investigation for determining the cause of such migrations of cod as occur between these two regions, particularly as these have taken place, according to our tagged fish, only during the summer.

TABLE 31.—*Various water temperatures, selected to show the wide difference between Nantucket Shoals and the Chatham-South Channel region, particularly in summer* [1]

Reference No.	Station [2]	Date	Position	Locality	Depth		Temperature	
					Meters	Fathoms	° C.	° F.
			° ′	*Nantucket Shoals*				
1	H 10647	Apr. 27, 1923		Rose and Crown buoy	0	0	3.3	37.9
2	A 20221	May 4, 1927		1½ miles SSE. from Round Shoal buoy	0	0	5.0	41.0
					15	8	5.4	41.7
					24	13	5.4	41.7
3		May 7, 1927		1½ miles SSW. from Rose and Crown buoy	0	0	5.5	42.0
					20	11	5.6	42.1
4		do		Rose and Crown buoy	0	0	5.5	42.0
					22	12	5.9	42.6
5		do		Great Rip buoy	0	0	5.5	42.0
					13	7	6.0	42.8
					22	12	6.0	42.8
6		June 7, 1925		1 mile SSE. from Round Shoal buoy	0	0	8.3	47.0
					30	16	8.4	47.1
7		June 17, 1927		Round Shoal buoy	24	13	9.1	48.4
8	H 10655	July 15, 1924	41 22 N.	10 miles ESE. from Round Shoal buoy	0	0	10.0	50.0
			69 32 W.		9	5	10.5	50.9
					18	10	10.5	50.9
					27	15	10.4	50.7
9		July 19, 1928	41 27 N.	Round Shoal buoy	0	0	11.7	53.0
			69 43 W.		22	12	11.9	53.4
10		do		Great Rip buoy	0	0	11.3	52.4
					9	5	11.6	52.8
					18	10	11.2	52.2
11	A 20361	July 21, 1928	40 53 N.	34 miles S. from Round Shoal buoy	0	0	12.8	55.0
			69 40 W.		10	5	12.8	55.0
					20	11	12.8	55.0
					40	22	12.8	55.0
12		Aug. 20, 1925	41 27 N.	Round Shoal buoy	0	0	11.6	52.8
			69 43 W.		13	7	11.4	52.5
					22	12	11.2	52.2
13		Aug. 21, 1925		1 mile E. from Round Shoal buoy	0	0	11.6	52.8
					9	5	11.6	52.8
					20	11	11.6	52.8
14		do		2 miles ENE. from Round Shoal buoy	0	0	11.7	53.0
					15	8	11.5	52.7
					25	14	11.7	53.0
15		do		1½ miles SSE. from Round Shoal buoy	0	0	13.3	56.0
					24	13	13.2	55.8
16		Aug. 23, 1925	41 21 N.	1 mile NE. from Rose and Crown buoy	0	0	16.4	61.5
			69 43 W.		22	12	15.6	60.0
17		do		Great Rip buoy	0	0	14.5	58.0
					22	12	14.6	58.2
18		Aug. 24, 1925		do	0	0	13.8	56.8
					13	7	14.2	57.6
					24	13	14.3	57.8
19		do	41 10 N.	4 miles E. from Great Rip buoy	0	0	13.9	57.0
			69 40 W.		15	8	14.1	57.4
					22	12	14.4	57.9
20		Sept. 2, 1927		Round Shoal buoy	0	0	10.0	50.0
					20	11	10.3	50.5
21		Sept. 7, 1926		½ mile NE. from Round Shoal buoy	11	6	13.9	57.0
22		Oct. 1, 1925		2 miles NE. from Rose and Crown buoy	0	0	12.2	54.0
					13	7	12.7	54.8
					26	14	12.8	55.0
23		do		1½ miles S. from Round Shoal buoy	0	0	11.6	52.9
					13	7	12.0	53.6
					24	13	12.0	53.6
24		do	41 24 N.	5 miles SE. from Round Shoal buoy	0	0	11.6	52.9
			69 37 W.		13	7	11.9	53.4
					26	14	13.5	56.3
25		Oct. 22, 1925		1 mile S. from Round Shoal buoy	0	0	10.8	51.4
					11	6	9.4	48.9
					22	12	9.4	48.9
				Chatham grounds				
26	A 20220	May 3, 1927	41 36 N.	13 miles NE. true from Round Shoal buoy	0	0	5.5	42.0
			69 31 W.		18	10	4.6	40.3
					36	20	4.4	39.9
					54	30	4.4	39.9
27		June 7, 1925	41 42 N.	6 miles E. true from Chatham Light	0	0	12.7	54.8
			69 48 W.		42	23	6.5	43.7
28		June 17, 1925	41 22 N.	15 miles E. by S. true from Round Shoal buoy	0	0	9.7	49.5
			69 23 W.		18	10	6.4	43.5
					33	18	6.3	43.3
29	A 20343	July 13, 1928	41 41 N.	13 miles E. true from Chatham Light	0	0	15.4	59.7
			69 39 W.		12	7	11.3	52.3
					47	26	5.9	42.6

[1] The temperatures prior to 1926 are from H. B. Bigelow, Physical Oceanography of the Gulf of Maine, 1927, Tables 4 to 18, pp. 978–1014. Also recorded in Bigelow 1915 and 1917.

[2] Station A=Albatross II; G=Grampus; H=Halcyon.

TABLE 31.—*Various water temperatures, selected to show the wide difference between Nantucket Shoals and the Chatham-South Channel region, particularly in summer*—Continued

Reference No.	Station	Date	Position	Locality	Depth		Temperature	
					Meters	Fathoms	° C.	° F.
			° ′	*Chatham grounds*—Continued				
30	----------	July 19, 1928	41 35 N.	12 miles NE. true from Round Shoal buoy	0	0	15. 8	60. 5
			69 32 W.		11	6	15. 4	59. 8
					16	9	13. 6	56. 5
					18	10	10. 8	51. 5
					22	12	9. 5	49. 1
					44	24	6. 6	44. 0
31	G 10085	Aug. 4, 1913	41 39 N.	12 miles E. from Chatham Light	0	0	17. 5	63. 5
			69 42 W.		18	10	6. 4	43. 6
					48	26	5. 8	42. 4
32	G 10257	Aug. 24, 1914	41 39 N.	6 miles E. from Chatham Light	0	0	20. 0	68. 0
			69 49 W.		25	14	6. 8	44. 2
				South Channel				
33	A 20345	July 16, 1928	41 16 N.	19 miles SE. by E. true from Round Shoal buoy	0	0	11. 6	52. 8
			69 23 W.		20	11	7. 0	44. 6
					45	24	5. 3	41. 5
34	G 10354	July 25, 1916	40 26 N.	57 miles SSE. true from Sankaty Head, Nantucket	0	0	13. 6	56. 5
			69 24 W.		30	16	8. 7	47. 7
					70	39	6. 1	43. 0
				Georges Bank (western part)				
35	G 10059	July 9, 1913	41 06 N.	68 miles SE. by E½ E. true from Chatham Light	0	0	13. 3	56. 0
			68 42 W.		27	14	12. 6	54. 6
					55	30	12. 6	54. 6
36	G 10347	July 23, 1916	41 06 N.	64 miles SE. by E. true from Chatham Light	0	0	11. 4	52. 5
			68 51 W.		30	16	10. 9	51. 6
					60	32	9. 6	49. 3
37	G 10348	-----do-------	40 49 N.	90 miles SE. by E. true from Chatham Light	0	0	11. 7	53. 0
			68 21 W.		25	14	11. 3	52. 4
					50	27	11. 2	52. 2
38	A 20212	Sept. 5, 1926	41 12 N.	68 miles SE. by E. true from Chatham Light	0	0	13. 9	57
			68 35 W.		13	7	14. 8	58. 6
					53	29	13. 7	56. 6

It can be seen from Table 31 that there is a striking difference in the summer temperature on bottom between Nantucket Shoals and the Chatham-South Channel region, the latter being much the cooler. If then cod on the shoals wish to avoid the relatively warm water (50° to 60° F.) that obtains there in summer they need migrate eastward only 10 to 15 miles to find an environment of about 40° to 45° F., and even a shorter distance to find intermediate temperatures. Yet, only a small part of the Nantucket cod population at times make this summer emigration, for it was only the years from 1923 to 1925 during this investigation that the number was at all appreciable, as only stragglers journeyed eastward from 1926 to 1928.

If a good series of temperatures had been obtained for each of these years some correlation between the warmth of the water and the tendency of cod to emigrate eastward from the shoals might have been found. But our records are too incomplete for such an analysis. It was found, however, that during 1925, which was the warmest year of the six, considerably more cod did move eastward into cooler water than during any of the other years of record. (See Table 20, p. 36.) But in spite of this result we have no substantial proof based on temperature alone that Nantucket cod shift ground to avoid warm water in summer.

So far as the tendency for cod to seek cooler water is concerned, the small differences that exist in the maximum temperatures on the shoals each summer appear to be of less importance than the average size of the adult and near-adult cod which make up the population there. For example, if the lengths of the cod caught by the *Halcyon* and the *Albatross II* are averaged for the three years from 1923 to 1925, when a perceptible emigration of Nantucket cod occurred to the eastward, and for the three years from 1926 to 1928, when fewer fish emigrated, the following result is obtained:

From 1923 to 1925 the weighted mean length of the 14,629 cod tagged on Nantucket Shoals was 26.6 inches. Recaptures of these fish reported from the Chatham-South Channel region throughout the same period amount to 83 fish, or 0.56 per cent of the total number tagged. (See Table 28 for length distributions.) From 1926 to 1928 the weighted mean length of the 7,599 cod tagged on the shoals was 22.43 inches. Recaptures of these fish reported from the Chatham-South Channel region throughout the same period amount to 7 fish, or 0.09 per cent of the total number tagged.

Although the percentages of recapture in both cases are very small, they are based on a large number of fish and involve a mean period of about one and one-half years in each case; hence are significant. Of chief importance is the fact that the proportion of cod which are known to have made this journey during 1923–1925, when their average size was 26.6 inches, was about six times as great as during 1926–1928, when the average size was only 22.4 inches. That this difference in the percentage of recaptures was not due to a corresponding difference in fishing intensity for the two 3-year periods has been pointed out on page 38.

Further evidence showing that there is a tendency for the larger Nantucket cod rather than the smaller to emigrate to the Chatham-South Channel region may be had from the following data: Out of 37 cod tagged on the shoals in 1924 and recaptured there in 1924 and 1925, 21 fish were 25 inches long or less, while 16 were 26 inches or more at the time they were tagged; the average size was 25.3 inches. Out of 18 cod tagged on the shoals in 1924 and recaptured in the Chatham-South Channel region in 1924 and 1925, 5 fish were 25 inches long or less, while 13 were 26 inches or more; the average size was 27.7 inches. Of the cod tagged on the shoals in 1925 good records were obtained for 25 local recaptures, and 15 of these fish were 25 inches long or less at the time they were tagged and 10 were 26 inches or more; the average size was 24.5 inches. In contrast to this, of 17 cod tagged on the shoals in 1925 and recaptured in the Chatham-South Channel region that same year, 5 were 25 inches long or less, while 12 were 26 inches or more; the average length was 27.4 inches.

According to these results, when Nantucket cod average upward of about 26 inches in length a larger proportion of them immigrate eastward into the cooler water of the Chatham-South Channel region than when the fish average smaller than this, and when in addition the summer is a warm one, as in 1925, it would seem that optimum conditions for this immigration prevail.

SIZE OF THE COD POPULATION ON NANTUCKET SHOALS

One of the most desirable results that can come from an investigation of this sort is a knowledge of the size of the cod population in the locality under consideration. Fortunately, for the Nantucket Shoals region we have obtained what seems to be sufficient data to give some idea of the general order of magnitude of the stock of grown cod that were present there from 1923 to 1928. In order to make such an estimate, there are, of course, both known and unknown factors that must be dealt with. Under the known we have the number of cod both tagged and recaptured by our own vessels, while under the unknown there are the reductions in the numbers of marked fish present on the tagging ground due to the fishery, natural deaths, and emigrations, which, if they could be closely estimated, would add considerable accuracy to the calculations.

In addition certain basic assumptions must be made, for whether the estimated population of the tagging grounds can be extended to include all the grounds on Nantucket Shoals depends on (*a*) whether we are justified in assuming that cod are equally abundant on all the ground in this region which appears to be suitable for them, and (*b*) whether the estimate of the total area of both the tagging grounds and all of the shoals is correct.

As for the first assumption, we have no definite data as to the density of cod on Nantucket Shoals except for the tagging ground, but it is known that fishing vessels make good catches in places other than this ground; in fact, most of the commercial catch of cod on the shoals is taken along the eastern and southern parts where no marking has been done. If, therefore, all the bottom on the shoals which supports cod, containing as it does some areas where the fish are concentrated and others where they are sparse, be averaged, it is probable that the density of cod in the region designated as the "tagging ground" is very much the same as that on any other part of Nantucket Shoals of about the same area and average depth.

With regard to the area of the tagging ground, it is estimated to comprise about one-fourteenth of the total, for almost all of our fishing there was done along a strip about 20 miles long and 2½ miles wide. The total area of cod bottom on the shoals is estimated at about 700 square miles.

An estimation of the size of the cod population on the tagging ground must depend largely on the number of marked fish that were present there, available for recapture, during the spring to fall of the years 1923 to 1929. Unfortunately, it is virtually impossible to gage this accurately, for we have scarcely any data that throw light on the degree of gain or loss in the number of marked fish present from year to year. We can, however, obtain some idea of what the minimum population may have been.

A hypothetical example may make this clear. Suppose, for instance, that all the cod tagged on Nantucket Shoals during one year disappeared by the next, but that virtually all these fish were available for recapture on the tagging ground during the summer when they were tagged. (We have some basis for making this last assumption, for most of the fish remain localized during the summer and the chief losses would be caused by natural deaths and by recaptures made by the fishery; these would probably be small in so short a time interval.) Under such circumstances, if 5,000 cod were caught and tagged on the shoals from the spring to the fall of one year you might say that, taking the whole period as a unit, an average of about 2,500 of them were available for recapture there by a tagging vessel during the course of its fishing on the shoals that year. If 20 of these fish were recaptured by the time the catch of 5,000 had been completed, then we might conclude that 1 fish out of each 250 within that area designated as the "tagging ground" had been marked. The total population of the tagging grounds would be, therefore, two hundred and fifty times the number of marked fish available, or 250 × 2,500, which gives a result of 625,000.

Applying this method of calculation to the number of cod actually caught, tagged, or recaptured by the tagging vessels on Nantucket Shoals as given in Table 32, the following interpretation might be made:

Table 32.—*The ratio of marked to unmarked cod on Nantucket Shoals, as found by the tagging vessels, together with the estimated number of marked fish that on the average, were available for recapture there* [1]

Year	Approximate catch of cod	Estimated Average of marked cod available for recapture	Marked cod recaptured by tagging vessels	Ratio of marked to unmarked fish
	Number	*Number*	*Number*	
1923	8, 100	3, 750	32	1:256
1924	3, 400	1, 550	38	1:89
1925	4, 400	2, 050	26	1:170
1926	1, 850	800	10	1:185
1927	5, 500	2, 850	53	1:104
1928	1, 050	500	19	1:55
1929	700	325	7	1:100
Average	3, 571	1, 689	27	1:132

[1] The number of cod caught by the tagging vessels includes the injured fish as well as those utilized for tagging, for it is upon the total catch that the ratio is based. The estimated number available for recapture, on the average, is approximately one-half of the actual number tagged during each year of record. The recaptures taken by the tagging vessels include tag-scarred fish as well as those bearing tags.

From 1923 to 1929 an average of 3,571 cod were caught annually by the tagging vessels on the regular tagging ground, among which 27 [12] bore tags or tag scars. This is a ratio of 1 marked fish to 132 that were unmarked. If an average of 1,689 fish (see Table 32) were available for recapture on the tagging ground the population of this ground, during the summer at least, might be set at 1,689 × 132, or about 223,000. If the assumptions are correct regarding the density of fish and proportionate area of the tagging ground with respect to all of the shoals, then the total population might be estimated at about 3,000,000 cod of marketable size.

This, however, should be looked upon as somewhere near the minimum number, based as it is on the supposition that of the cod present one summer on the tagging ground virtually none remain until the next. But not all the individual cod present one summer have left the shoals by the next, for although about 7 per cent of the marked fish were taken annually by the fishery (2.29 per cent were actually reported and the remainder include the estimated number of tag-scarred fish and those with tags which were not reported), part of them die from natural causes, while others emigrate to other regions. Recaptures made on the tagging ground one and even two years later (Table 23) show that part of the cod either remain for that length of time or reappear there.

What proportion of the fish remain on the tagging ground from one year to the next is not known, and any attempt to determine this by calculations based on recaptures made one or two years after marking by the tagging vessels would be subject to error due to loss of tags. However, the returns of tagged cod give at least a minimum idea of the carry-over from one year to the next. From Table 23 it may be calculated that the recaptures during the second year after release average about 50 per cent as high as during the first season. The persistence of characteristic size groups in frequency distributions also indicates a substantial carry-over from one year to the next. If we assume that there were available for recapture not only most of the fish marked the same year but in addition about 50 per cent of the fish that were marked the year before, then the summer cod population of the shoals could be estimated at 4,500,000. Probably the average population of the shoals lies between 3,000,000 and 4,500,000 cod.

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[12] A large part of these were recaptured 6 months or more after tagging, and so fit rather well with the other data.

It is of course, not practicable to set a numerical value for the average number of cod present on Nantucket Shoals during each year of this investigation as many unknown factors were involved, but if the deductions just given are substantially sound they will give a general idea of the population's general order of magnitude.

It would be interesting to know what proportion of the grown fish are lost to Nantucket Shoals each year by deaths and emigrations, for whatever their number may be they seem to be replaced by other fish, thus keeping the population at somewhere near an equilibrium. (See catches per unit of effort made during the summer, Table 25, p. 44.) It appears, therefore, that immigrants and small fish growing to market size on Nantucket Shoals are enough to maintain the stock there, so at the present time there is no apparent reason for believing that this ground is overfished.

ORIGIN OF NANTUCKET SHOALS COD

The means by which the cod population may be kept up on Nantucket Shoals or on any other cod ground are (*a*) local production, (*b*) the drifting of fry from other regions, (*c*) the immigration of bottom fry, and (*d*) the immigration of older fish. Any one or two of these sources may prove to be of considerably more importance than the others, depending on various factors, but particularly on the geographic location of the ground in question and on the hydrographic conditions which obtain.

The important part played by these latter—that is, temperature and currents—in the distribution of fish eggs and larvæ is well known to all who have worked on such problems. (See Bigelow, 1926, p. 69–78.) The fact that cod eggs and larvae may be carried long distances from the place they were produced, has been illustrated by Schmidt's (1909, p. 22) results when he found large numbers of cod eggs and fry on the north and east coasts of Iceland, although spawning takes place only on the south and west coasts. And, as the bottom fry of the cod have been found in large numbers in the Baltic and in the White Sea, where adult fish seldom, if ever, spawn, the number of larvæ transported by the currents must be vast in some cases, as Damas (1909, p. 127) points out.

The same currents which carry the eggs and larvæ passively along also probably control to a large extent the destiny of the young fry, although as these near the bottom stage they evidently are able to govern their vertical migrations, if not their horizontal. Sars (1869), in his classic account of the Norwegian cod, found that the first few days after hatching the larvæ are kept at the surface by the yolk sac, but after this is absorbed they begin a more independent existence, although they are not able to resist the currents. Schmidt (1909, p. 20) found that the youngest or earliest stages are found nearest the surface and the larger ones farther down. M'Intosh (1897, p. 194), speaking of cod larvæ in Scottish waters, states that by the time they are as small as one-half to three-fourths of an inch, they may descend considerably in the water. This general thesis has since been corroborated by many observers, both in Europe and in America. The smallest cod taken on bottom in the North Sea by Graham (1926, p. 12) were 30–52 millimeters (1⅕–2 inches) long.

It is a general belief that it requires about six to eight weeks from the time cod eggs are hatched until the fry reach the permanent bottom-dwelling stage, though there is certainly much variation in this respect.

LOCAL PRODUCTION OF COD ON NANTUCKET SHOALS

Cod spawn on Nantucket Shoals from November to April, but chiefly during December and January. As the circulation of the water and to some extent its temperature on and near Nantucket Shoals, govern the destiny of the cod eggs spawned there, it will be of interest to consider whether many of the resultant eggs and larvæ may be expected to remain there in large numbers and so to maintain the stock of Nantucket Shoals cod by local production, or whether they tend to drift away.

For the winter period we have almost no data on the nontidal current for the Nantucket Shoals region that would bear on the drift of cod eggs spawned there other than that compiled by Bigelow (1927, p. 864) from the current measurements made by the United States Coast and Geodetic Survey in 1913–14 at Nantucket Lightship. These measurements, each of 29 days' duration, showed a dominant set averaging 5.3 miles per 24 hours N. 86° W., during October, when very few cod spawn on the shoals, while during each of the months from November to March, with the exception of January, covering the chief spawning season, the set was toward the east and south quadrant, its mean direction S. 51° E.; its mean velocity 2.6 miles per day. In the spring, by which time nearly all the local spawning has been completed, the set was again toward the north and west, the average for April being N. 75° W. at 1.4 miles and for May N. 62° W. at 4.3 miles per 24 hours.

It is true that in the summer Bigelow (1927, fig. 174) found that the dominant drift divides on Nantucket Shoals, one part going in a general westerly and the other in a general easterly direction. But as we have no proof that this condition obtains in winter, and some indication that it may be altered, no sound discussion on the subject, for that season, can be given at the present time.

A good series of winter temperatures is lacking for Nantucket Shoals, but, judging from the 10° to 12° C. surface records obtained in October, it is probable that they would range from an average of about 8° C. for November to the 2° to 3° C. obtained in late February (1929) by the *Albatross II.* The incubation period for cod eggs at these temperatures ranges from about 11 to 23–28 days.

If the Nantucket Lightship winter-current measurements are typical for most of the shoals each year, then it is apparent that the southeastward drift of 2½ to 3 miles per day would carry off most of the cod eggs spawned there before they hatch and that the resultant fry would travel considerably farther before reaching the bottom stage. Consequently, it may be accepted that only a negligible part of the cod living on Nantucket Shoals grow up there from eggs produced locally. Hence, we must look elsewhere for the source of the small cod fry that are known to be present on Nantucket Shoals in the summer (p. 91).

THE PROBABLE DRIFT OF COD FRY FROM OTHER REGIONS TO NANTUCKET SHOALS

It is probable that during most of the winter almost every square mile of water off the New England coast contains some cod eggs, larvæ, and fry; for spawning occurs on suitable grounds, both inshore and offshore, over a large part of the Gulf of Maine and through a period extending from October to April or May. The number of fish which spawn in this region each year is very large and the number of eggs produced is enormous.

Given favorable currents, any area in the Gulf of Maine is thus a potential source of supply for any cod ground there; hence for Nantucket Shoals the question of the circulation of the water is the crucial one in this connection. More specifically, whether or not Nantucket Shoals is particularly favored with cod fry depends upon whether the nontidal drift flows toward that region from important spawning grounds far enough away for the eggs and larvæ to develop into bottom-dwelling fry by the time they reach the shoals.

For determining the general circulation of the ocean off the New England coast numerous drift-bottle and current-meter experiments have been made by Bigelow and others. The drift-bottle experiments at best can give but a rough picture of the circulation of the upper stratum. Conditions may change from day to day, so that an average result, covering perhaps one to two months of time, is all that can be obtained as to routes and velocities between the setting out and recovery of the bottles. However, it is almost certain that part of the drifting cod eggs, larvæ, and to some extent the fry, follow the same route as the bottles. Up to the present the experiments made with these latter furnish our most dependable means of tracing the destiny, in a general way, of the cod spawn discharged in any particular part of the Gulf of Maine.

Bigelow (1927, p. 972) found that the Gulf of Maine is dominated by an anticlockwise nontidal circulation, differing in velocity and in detail with the season. A rough picture of the circulation in July and August is given in Figure 26. As the currents from offshore do not pass over the cod grounds south of Cape Cod, except possibly by a long and tortuous course, they are not treated here. To the westward of Nantucket, although little is known of the conditions existing in winter, the fact that Bigelow found a shore drift to the Rhode Island-North Carolina region in summer, carrying flotsam away from the shoals, suggests that this region does not constitute a prolific source for Nantucky Shoals fry. A large number of cod spawn in this westward region, so that a study of its hydrography presents an important problem for the future.

The dominant drift in the Gulf of Maine, which sets in a southwesterly direction along the coast of Maine, veers to the eastward well off Cape Cod, and thence toward Nova Scotia, but part of it follows the coast southward past Cape Cod and down to Nantucket Shoals. It is this part of the drift that is of most importance in bringing to Nantucket Shoals pelagic cod fry originating from eggs spawned to the northward of Cape Cod.

In late winter and early spring the northeast-southwest drift along the coast of Maine and southward past Cape Cod is most definite and reaches its greatest velocity of the year. Bigelow (ibid., p. 975) states that "under these circumstances flotsam of any kind (buoyant fish eggs, for instance, or the larvæ hatched therefrom) that may drift from the north into the northern side of Massachusetts Bay or that may be produced there tends to drift out of its southern side." This being so, we have favorable conditions for the drift of cod fry to Nantucket Shoals from regions north of Cape Cod, providing that the velocity of drift is such that the resultant fry will reach the southern Massachusetts region at a time when they are seeking the bottom.

With regard to the velocity of the dominant nontidal drift in the Gulf of Maine in so far as it affects the destiny of cod fry, the year falls into two periods—a winter season from October to May, when prevailing northwesterly winds enhance the speed of the current along the shores of Maine and Massachusetts and hold it close in, and a summer season from June to September, when prevailing south and southwesterly winds both retard it and direct it offshore.

The following velocities for the winter and spring have been obtained for the region between the Bay of Fundy and Nantucket Shoals.

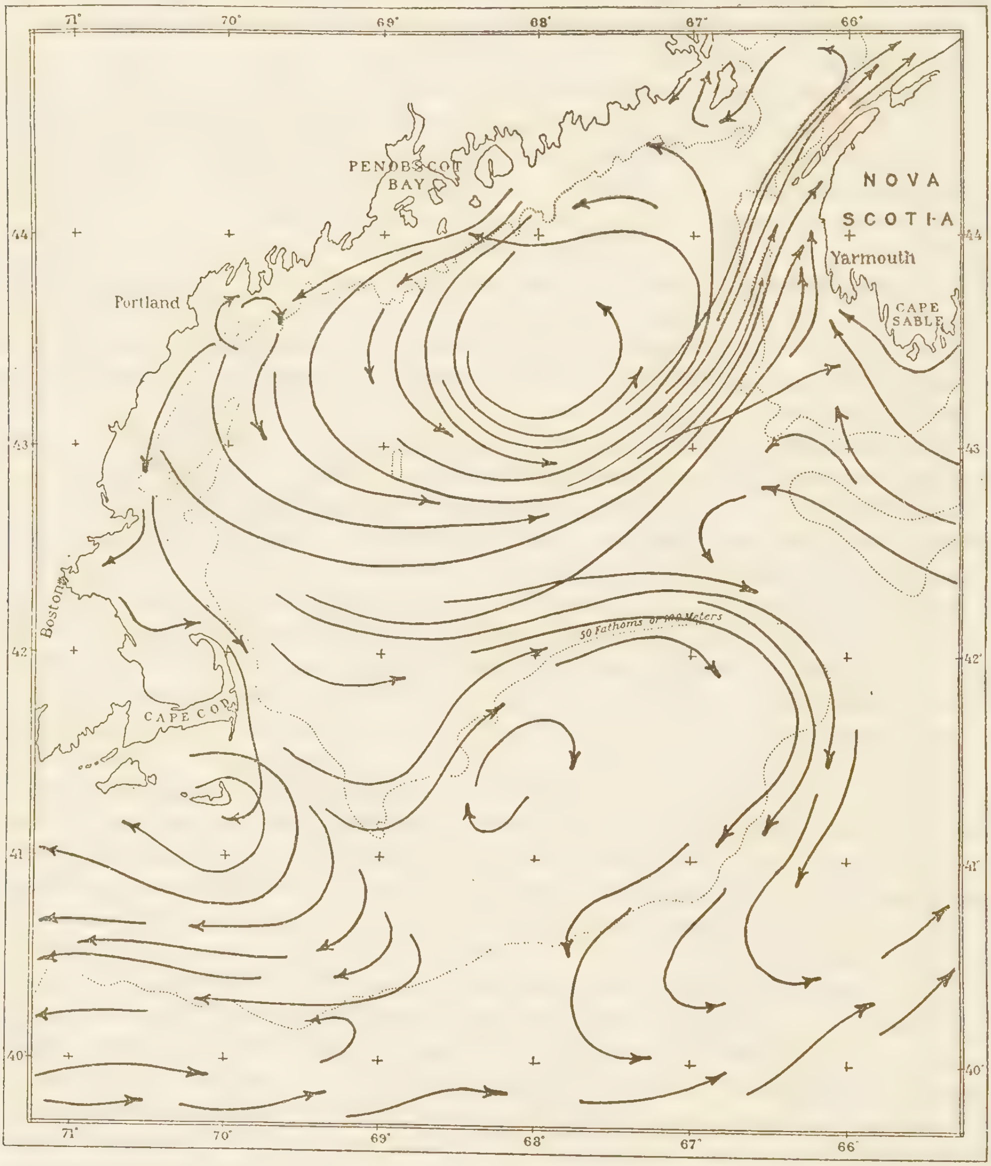
71°
70°
69°
68°
67°
66°
44
43
42
41
40
PENOBSCOT BAY
Portland
NOVA SCOTIA
Yarmouth
CAPE SABLE
Boston
CAPE COD
50 Fathoms or 100 Meters

FIGURE 26.—Schematic representation of the dominant nontidal circulation of the Gulf of Maine, July to August. (After Bigelow, 1927)

At Portland Lightship measurements made by the United States Coast and Geodetic Survey (Bigelow, 1927, p. 861) show a mean dominant set of about 8 miles a day to the south and west from October to December of two different years. According to prevailing winds, the October-December conditions probably continue until May.

Recoveries from a line of drift bottles run 10 miles off Cape Ann, Mass., in April, 1926 (Bigelow, ibid., p. 878), showed the following periods of drift between there and the Nantucket Shoals region: 1 bottle was recovered 32 days later at Race Point, Cape Cod, a distance of about 37 miles, or an average velocity of 1.15 miles per day;[13] 2 bottles went to Chatham, 70 miles, in 30 and 38 days, respectively, at an average for the two of 2.09 miles; another was taken off Monomoy, Cape Cod, after 49 days, 75 miles, at 1.53 miles per day; 2 reached the island of Nantucket, the mean rates being 57 days, 115 miles, at 2 miles per day; and another went to the south shore of Marthas Vineyard in 74 days, about 130 miles, at 1.76 miles per day.

The following results were obtained from a line of drift bottles set out in Massachusetts Bay February 6 and 7, 1925 (Bigelow, 1927, p. 876, and Fish, 1928, p. 277): Out of 90 bottles 27, or 30 per cent, were recovered, of which 4 went around Cape Cod or toward the Nantucket Shoals region. Of these 1 was reported 29 miles east-southeast from Stellwagen Bank (there is some doubt about the exact locality of recovery) 9 days later and about 49 miles away, a velocity of 5.4 miles per day; 2 were taken on the south shore of Nantucket, 88 miles in 128 days, and 80 miles in 144 days, respectively, from the place and time of release, an average velocity of 0.62 mile per day (these latter may have been delayed inside the arm of Cape Cod or elsewhere); and 1 was recovered after 149 days, off Fire Island, N. Y., and had traveled about 220 miles, at an average velocity of 1.48 miles per day.

In May, 1925, drift bottles were put out in various parts of Massachusetts Bay. (Bigelow, 1927, p. 877, and Fish, 1928, p. 278.) The recoveries include 2 bottles which crossed the bay in 5 and 6 days, at a velocity of 3.6 and 2.5 miles, respectively; 1 bottle went from the southern tip of Stellwagen Bank to 75 miles southeast by east from Cape Cod Light (which places it in South Channel), a distance of about 90 miles in 22 days at 4.1 miles a day; another went to Dennisport, on the southern coast of Cape Cod, about 80 miles in 17 days at 4.7 miles per day; while another was found near Edgartown, Marthas Vineyard, 65 days later, a distance of about 120 miles from its place of release near the middle of Cape Cod Bay, and average velocity of about 1.8 miles per day.

In addition to these drift bottle records, current measurements by the United States Coast and Geodetic Survey (Bigelow, 1927, p. 864) were made along the outside coast of Cape Cod. That the current runs strong there is shown by the 12 miles per day southward drift that was obtained off Nauset Light. Current measurements taken from June to September, 1911, at Pollock Rip Lightship and at Round Shoal Lightship, which are on the fringe of Nantucket Shoals at the entrance to Nantucket Sound, showed a dominant drift toward the southeast at velocities of 9 to 10 and 2 to 3 miles per 24 hours, respectively.

As a result of these various bottle experiments and current measurements there is some evidence that during the winter and spring the velocity of that part of the dominant drift which sets southward along the coast of Maine and out and around Cape Cod to southern Massachusetts is of about the following order of magnitude: About 5 to 8 miles per 24 hours from eastern Maine to Cape Ann, 2 to 5 miles across Massachusetts Bay to the north tip of Cape Cod, and about 2½ miles from Cape Ann to the Nantucket Shoals region. The latter rate is based on the average velocity of eight bottles which drifted from Cape Ann and Massachusetts Bay to South Channel, Nantucket, and Marthas Vineyard.)

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[13] These are minimum velocities, for, no doubt, some of the drift bottles were anchored on the shore for some time before they were found.

According to these velocities, it is evident that fry coming from eggs spawned between eastern Maine and Cape Cod are carried to Nantucket Shoals in a relatively short time. Many of them, no doubt, drift far beyond before attaining the bottom-dwelling stage. Fish (1928, p. 283) found newly spawned cod eggs in the western part of Massachusetts Bay and late embryos in the eastern part and concluded that the anticlockwise drift carried them out of the bay before they hatched. We have

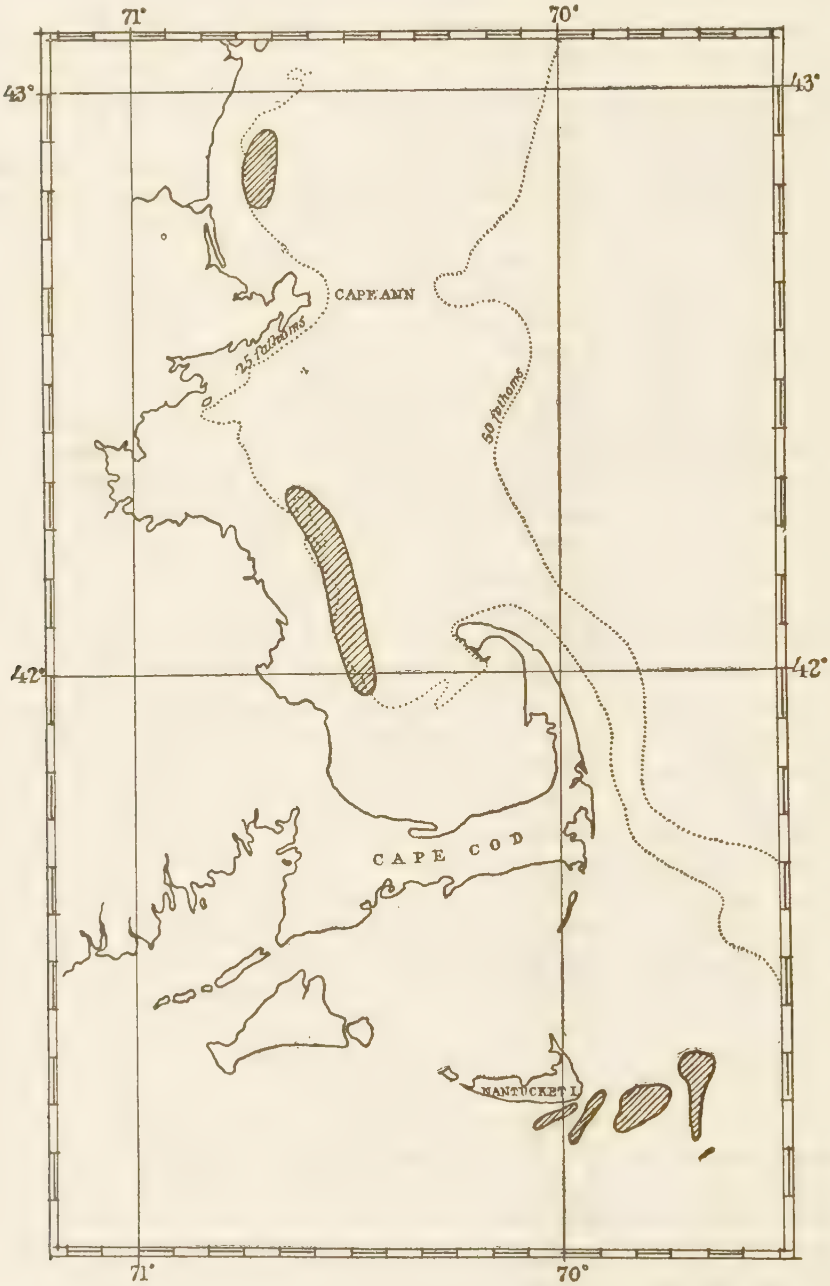

FIGURE 27.—Chief spawning grounds of cod in the western side of the Gulf of Maine. (After Bigelow, 1925)

also the catches of cod larvæ[14] made by the *Albatross II* along the outer coast of Cape Cod. These included a catch on May 28, 1927, off Race Point, of 148 larvæ 3½ to 6½ millimeters long, taken in one haul, and another off Cape Cod Light on the same date of 194 larvæ which measured 3½ to 9½ millimeters. It is apparent from the size of these larvæ that they would be carried beyond the Nantucket region by the time they reached the bottom stage.

It is safe to assume that most of the eggs spawned north of Cape Cod hatch in 15 to 30 days, depending on the season and, therefore, the temperature. If approximately 50 days are allowed for the development of the larvæ and fry, it can be seen that spawning grounds located 65 to 80 "drift days" away and in line with the southerly drift are well situated for supplying southern Massachusetts with fry. Exceptions, of course, would occur, for the velocity of drift might be greater some months than others; eggs spawned early in the season might hatch in as little as 10 days; and delays en route, such as might be caused by eddies, would enhance or retard the chances of fry reaching the shoals, depending upon how far they had to drift.

Along the course of the southerly drift there are various important spawning grounds. Farthest north and east, between Cape Elizabeth and the Bay of Fundy[15] the grounds are scattering and small, but in the aggregate a large number of cod eggs are probably produced there. More important spawning grounds are located between Cape Ann and Cape Elizabeth (chiefly in Ipswich Bay), and others between Cape Ann and Cape Cod. (Fig. 27.)

Although cod spawn throughout the winter in most localities, the time when the height of egg production occurs may vary even on two grounds close together. Thus Bigelow (1924, p. 422) shows that on the north side of Cape Ann ripe fish are not common until January or February and much of the spawning occurs from February to April, while off Plymouth, only 50 miles distant, the important part of the season usually is in January and February. Fish (1928, p. 290) found considerable spawning taking place off Plymouth as early as November 12, in 1924. Between Cape Elizabeth and the Mount Desert region most of the spawning takes place from March to May.

Variation in the incubation period of the eggs (see Table 33), according to temperature, makes it pertinent to consider the approximate conditions which exist over the spawning grounds which lie in the path of the drift toward Nantucket Shoals at the time of spawning.

TABLE 33.—*Period of incubation for cod eggs*[a]

Water temperature		Days	Water temperature		Days	Water temperature		Days	Water temperature		Days
°F.	°C.		°F.	°C.		°F.	°C.		°F.	°C.	
31	−0.6	50	36	2.2	25	41	5.0	16	46	7.8	11
32	0.0	40	37	2.8	23	42	5.5	15	47	8.3	10–11
33	+0.6	35	38	3.3	21	43	6.1	14			
34	1.1	31	39	3.9	19	44	6.7	13			
35	1.7	28	40	4.4	17	45	7.2	12			

[a] From A Manual of Fish Culture, p. 206, in Report U. S. Commissioner of Fisheries, Pt. XXIII, for 1897.

[14] These larvæ were discovered among plankton hauls made by O. E. Sette during mackerel investigations.

[15] Because of the unusual physical conditions of the water in the Bay of Fundy, larvæ from pelagic eggs are rare there. (See Huntsman, 1918c, p. 65.)

The coast of Maine from the Bay of Fundy to Cape Elizabeth.—For this long stretch of coast it is difficult to set an average time and place for the spawning of the cod or an average temperature. Cod eggs spawned there in March would hatch in about 25 to 31 days in the 1° to 2° C. temperatures prevailing, 16 to 19 days in 4° to 5° C. water in April, and 11 to 14 days in 6° to 8° C. water in May. The distance from this region to Nantucket Shoals, over the shortest route that can be taken by the dominant drift, is about 180 to 360 miles. Arbitrarily assuming an average drift rate of 3 miles per day, it would require 60 to 120 days for flotsam to cover the distance from this region to the shoals. Allowing an incubation period of 12 to 28 days for the eggs and a pelagic existence of about 50 days for the larvæ and fry, they would travel 62 to 78 days before the latter reached the stage when they seek bottom.

This region, therefore, constitutes one of the most probable sources of the cod fry found on bottom on Nantucket Shoals.

Cape Elizabeth to Cape Ann.—Eggs spawned in this region in January, drifting southward and around Cape Cod, would incubate in a temperature averaging around 3° C., while in February and March it would be closer to 2° C. During the principal part of the spawning season, therefore, hatching would there require about 23 to 28 days. The center of this region is about 150 miles distant from the shoals, along the probable route of the drift, which at an average velocity of 3 miles a day would carry flotsam to Nantucket Shoals in about 50 days. Allowing 73 to 78 days of drift for the eggs, larvæ, and fry, it appears that most of the latter would pass well beyond the shoals before seeking bottom and, consequently, that this region is less favorably situated than the preceding with respect to stocking the shoals with cod fry.

Massachusetts Bay region.—Cod eggs spawned here as early as November would hatch in about 10 days in 9° C. water, while in December the period would be 14 to 19 days, for the temperature then ranges from 4° to 6° C. In January and February, when much of the spawning occurs in this region, the temperatures along the route to Nantucket Shoals average about 2° C.; hence the incubation period occupies 25 to 28 days. The distance from both the Plymouth grounds and Stellwagen Bank to Nantucket Shoals is about 80 miles, and the time required for flotsam to accomplish the drift at 3 miles per day would be about 27 days. From the time the eggs are spawned there cod fry would drift about 60 to 75 days before taking to the bottom, by which time those which passed over the shoals would probably go far beyond. It seems clear that this region is much less favorably located than others farther north for supplying the shoals with cod fry.

These estimates, rough at the best, are meant to apply to the principal spawning grounds along the western part of the Gulf of Maine, to the height of the spawning period, and to the approximate velocity of the dominant drift along a direct course. For example, spawning on most of the grounds progresses throughout the winter, so that while as many eggs, or more, may be deposited during one or two months (when the season is at its height) as during the rest of the season combined, the secondary period, in the aggregate is very important. And it is possible that fry may at such times reach the shoals from grounds that do not contribute to the former at the height of the breeding season.

Although many cod fry are carried past Nantucket Shoals by the dominant drift, the probability must not be overlooked that some of these seek bottom near by and thus are an important factor in keeping up the stock of cod off southern New England in general, if not on Nantucket Shoals in particular.

In sum, cod eggs spawned along the coast of Maine east of Cape Elizabeth are probably the most prolific source of the cod fry present on Nantucket Shoals.

THE PRESENCE OF JUVENILE COD ON NANTUCKET SHOALS

In American waters little is known concerning the habits and migrations of young cod from the time they first take to the bottom until they are about 2 years old (about 12 to 14 inches long). Consequently, we must turn to European sources for information as to this stage in the cod's life.

Off the Norwegian coast, Hjort and Dahl (1900, p. 154), in summing up Sar's findings on the cod, point out that cod fry approach the shores in summer and in autumn when about 10 to 12 centimeters (about 4 to 5 inches) long. They live close by the shore in sandy bays and in the uppermost seaweed. McIntosh (1897, p. 194–195) states that in Scottish waters the fry frequent shallow rock pools, but that they go offshore as they become older. Schmidt (1907, p. 16) records cod fry 4 to 5 centimeters (1½ to 2 inches) long in the fjords around Iceland in September, while various European investigators mention the presence of young fry floating under jellyfish (Cyanea). Not all records of the fry have been from alongshore, for Hjort (1914, p. 10) states that, although the younger stages live as a rule in shallow water in the southerly regions, observations made to the northward (east of Vardo and in the Varanger Fjord) have shown that small cod, from the earliest bottom stages upward, are to be found widely distributed throughout great parts of the Barentz Sea, even as deep as 100 to 200 fathoms.

How closely the habits of European and American cod fry agree, particularly with respect to the environment in which they pass their first year, is not yet known. We have no proof that cod fry make extensive migrations off the New England coast. Comparatively few have been found in the immediate shore waters during recent collecting, although offshore they were quite generally scattered over all good cod bottom wherever experimental hauls were made between Nantucket Shoals and southern Nova Scotia.

A few hauls made on Nantucket Shoals with a small otter trawl [16] yielded the following young cod:

Haul No. 1.—June 22, 1927; 10 miles east of Round Shoal buoy; one-half hour; depth, 21 fathoms; 5 cod, 63 to 93 millimeters long (2.5 to 3.7 inches).

Haul No. 2.—June 24, 1927; near Great Rip buoy; one-half hour; depth, 12 fathoms; 14 cod, of which 12 were 61 to 122 millimeters (2.4 to 4.8 inches) and the other two, 297 and 343 millimeters long (11.7 and 13.5 inches).

Haul No. 3.—October 16, 1927; near Great Rip buoy; one-half hour; depth, 12 fathoms; 2 cod, 184 and 203 millimeters long (7.2 and 8 inches).

In addition to the fry taken in trawls others were found in the stomachs of larger fish, chiefly cod. As a rule about 8 or 10 young cod from about 3 to 7 inches long were found per 100 stomachs examined not only in cod caught on Nantucket Shoals but in many other localities as well.

Although small cod less than 8 inches long and not over about 1 year of age have been found quite generally distributed over Nantucket Shoals and other offshore grounds, only a small part of them appear to survive there, for a striking paucity of fish a little larger, between 8 and 15 inches long or 1 and 2 years of age, has been found. This is illustrated by the following list of the smallest cod which we caught on Nantucket Shoals with hook and line:

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[16] The trawl used had a spread of about 30 feet between the boards and was of ¾-inch square mesh. Usually the cod end was lined with bobbinet of about 3⁄32-inch mesh.

TABLE 34.—*The total catch of cod less than 16 inches long taken by the "Halcyon" and "Albatross II" on Nantucket Shoals from 1923 to 1928 with hook and line*

Date	Cod caught	Number below 16 inches [1]					
		11 inches	12 inches	13 inches	14 inches	15 inches	Total
1923:							
April-May	336	-----	-----	-----	1	-----	1
May	411	-----	-----	-----	-----	-----	-----
June	1,144	-----	-----	-----	2	-----	2
August	1,790	-----	-----	-----	-----	-----	-----
September	1,352	-----	-----	-----	-----	-----	-----
October	2,521	-----	-----	-----	-----	-----	-----
1924:		-----					
July	1,254		-----	-----	-----	-----	-----
September	964	-----	-----	-----	2	-----	2
October	884	-----	-----	4	12	18	34
1925:							
May	852	-----	-----	-----	3	7	10
June	671	-----	1	-----	1	3	5
August	1,291	2	3	9	15	16	45
October	1,328	-----	-----	9	36	47	92
1926:							
September	1,878	-----	-----	-----	2	17	19
1927:							
May [2]	1,252	-----	-----	-----	-----	-----	-----
June [2]	1,701	-----	-----	-----	-----	2	2
September	1,468	-----	1	2	1	2	6
October	1,291	-----	-----	-----	2	-----	2
1928:							
July	748	-----	5	-----	-----	7	12
October	304	-----	1	1	16	13	31
Total	23,440	2	11	25	93	132	263

[1] None were caught under 11 inches.
[2] In addition there were caught on the Chatham grounds 460 cod, which included one 14 and one 15 inch fish.

The question naturally arises as to what extent selectiveness of the hook-and-line gear is responsible for the very small proportion of cod below 16 inches that was taken, for we found fish so small to be scarce not only on Nantucket Shoals but in all our catches made on the offshore banks as well. Alongshore the results have been much different, for there we have caught large numbers of cod 12 to 15 inches long with the same sort of hooks as was used in the Nantucket region. For example in the shore waters off Mount Desert, Me., where we caught 9,894 cod from 1924 to 1928, a total of 38 per cent of the cod (compared with 1 per cent for Nantucket Shoals, was less than 16 inches long, divided according to size, as follows: 10 inches, 5; 11 inches, 76; 12 inches, 416; 13 inches, 959; 14 inches, 1,163; and 15 inches, 1,139 fish.

The scarcity of these small cod in our catches on Nantucket Shoals and other offshore grounds might be due, to a small extent, to the aggressiveness of the large fish in seizing the bait, but this possibility fails to explain the vast difference in the percentage of young fish taken in the shore waters as compared with the offshore.

It will be of great importance to know with certainty what now seems a probability, namely, whether the large numbers of cod fry scattered over our offshore banks are almost completely wiped out by the depredations of larger fish, for if this be so our stock of adults must be drawn largely from the nurseries alongshore such as that along the coast of Maine. More sampling must be done with nets as well as with various sizes of hooks before we can hope to answer this question. Observations along this line were made in September, 1929, when I observed the catches in 40 hauls made by a commercial otter trawler on the northeastern part of Georges Bank. Although the bunt of the net used was of a mesh fine enough (1 inch square) to retain cod at least as small as 10 inches in length, only a few hundred (fig. 28) were small enough to fit in the 10 to 15 inch class. (The catch of cod consisted of several thousand fish, nearly all of them between 18 to 45 inches long.)

It seems apparent that only to a small extent do the cod fry which seek bottom on Nantucket Shoals contribute to the stock of fish there, for, whatever may happen to them, few survive on the shoals after they reach about 1 year of age. Consequently, the population must be kept up largely by the immigration of older cod (young adults and near adults) from other localities. A discussion of these follows.

IMMIGRATIONS TO NANTUCKET SHOALS OF ADULT AND NEARLY ADULT COD

That schools of medium-sized cod appear on Nantucket Shoals from time to time was learned from the length-frequency distributions of the fish caught by the *Halcyon* and the *Albatross II*. Unfortunately, none of these fish bore tags from other grounds; hence, definite information as to their source is lacking. However, recaptures taken along a route to Nantucket Shoals and beyond of cod tagged to the north and east of Cape Cod throw some light on this question. Their records follow.

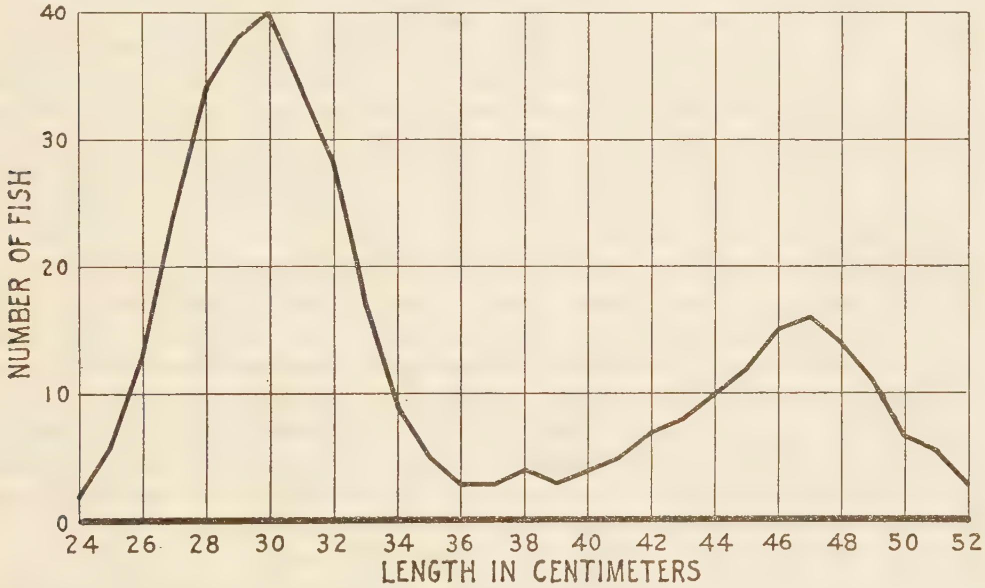

FIGURE 28.—Length-frequency distribution of the young cod caught in an otter trawl during the course of a week's fishing on northeastern Georges Bank September 19–25, 1929. Smoothed once by a moving average of 3

Year 1923.—Only 12 cod were tagged on grounds other than Nantucket Shoals during 1923—all on Stellwagen bank (between Cape Cod and Cape Ann). Out of the three recaptures subsequently made one fish was taken at Rockaway, N. Y.

Year 1924.—A total of 3,144 cod was tagged along shore between New Hampshire and Mount Desert, Me., and on the following offshore banks: Stellwagen Bank, Boone Island, Jeffreys Ledge, and Platts Bank. There were 396 recaptures reported, of which the following fish migrated toward or past Nantucket Shoals: 2 fish were taken 10 to 23 miles off Highland Light, Cape Cod; 2 off Chatham, 3 in South Channel, 2 near Round Shoal buoy on Nantucket Shoals, and 1 at Rockaway, N. Y. In addition a southerly direction was taken by one of the fish tagged near Portland, which was recaught on Stellwagen Bank, and by 2 Mount Desert cod, 1 of which was taken on Jeffreys Ledge and 1 on Platts Bank.

Year 1925.—A total of 6,389 cod was tagged on the same grounds north of Cape Cod as in 1924, of which 918 were subsequently reported recaptured. Of these 1 Stellwagen cod was taken off Atlantic, City N. J., and there is a somewhat doubtful record of a Mount Desert fish taken off Race Point, Cape Cod. In addition, Mount Desert cod were taken, 1 each at Matinicus, Portland Lightship, and Ipswich Bay.

Year 1926.—Tagging was restricted somewhat this year, and the number of cod tagged other than on Nantucket Shoals amounted to 1,016 on Georges Bank and 945 off Mount Desert. The subsequent recaptures numbered 169 and included 1 Georges Bank cod, which was taken off Rhode Island, and 1 Mount Desert fish, which was caught off Matinicus, Me.

Year 1927.—A total of 3,190 cod was tagged in the following localities: Georges Bank, Browns Bank, Cashes Ledge, Jeffreys Ledge, Platts Bank, Stellwagen Bank, and off Mount Desert. The recaptures reported numbered 298, of which 2 came from South Channel. In addition, a Browns Bank cod was taken off Magnolia, Mass., and a Platts Bank cod was taken off Plymouth, Mass.

Year 1928.—During this year 1,285 cod were tagged in the Gulf of Maine, north and east of Nantucket Shoals and South Channel; and from these 33 recaptures were reported, of which 4 were taken along the route to Nantucket Shoals. Two of these were cod from the northeastern part of Georges Bank, 1 of which was taken on the southwestern part of the bank and 1 on Nantucket Shoals. One cod migrated from Cape Sable, Nova Scotia, to the Chatham grounds, while another migrated from Stellwagen Bank to Rhode Island.

This summary shows that only 29 tagged cod out of 1,817 recaptures reported from 15,981, marked on grounds other than Nantucket Shoals and Chatham, from 1923 to 1928, showed a tendency to migrate toward Nantucket Shoals. Of these 29 only 19 cod, or about 1 per cent of the total recaptures, were taken in the Nantucket-Chatham-South Channel region proper and on the wintering grounds to the westward. This result, taken by itself, would seem to indicate that no important migration to Nantucket Shoals occurred from any of the grounds where we have tagged a large number of fish to the north and east throughout the six years of this experiment. However, if the region north and east of Massachusetts be taken by sections the dispersals made by these fish take on added interest.

Only 5 cod out of about 10,000 that were tagged along shore between Cape Elizabeth and Mount Desert, Me., were recaptured along a route to southern Massachusetts. This region, therefore, is not a likely source of the young adult cod which appear on Nantucket Shoals from time to time. Although the coast of Maine appears to play an unimportant rôle with regard to supplying Nantucket Shoals with adult cod, we must not lose sight of the fact that the shore waters there form one of the greatest nurseries for young cod along our coast, and that most of the 10,000 fish which were tagged off Mount Desert were younger (3 years old or less) than the cod tagged elsewhere in the Gulf of Maine. It may be that as these fish grow older, reaching upward of 4 years of age and move out into deeper water, that many of them may find their way into the southern Massachusetts region, probably by way of the offshore banks. Direct evidence of this from marked fish is lacking, because nearly all these fish would have lost their tags during the long period elapsing before their meanderings could bring them to the Nantucket region.

A small proportion of the cod living on Platts Bank and Cashes Ledge, and probably in their general vicinity, emigrate toward southern Massachusetts, for 6 tagged cod (out of 1,600 marked) from these banks were recaptured along the coast of Cape Cod.

If some of the cod from the north and east of Cape Cod which migrate to the wintering grounds between Rhode Island and North Carolina drop off, either on their way southward or on their return northward, to live on Nantucket Shoals, then the stock of fish in this latter region is kept up partly by grown fish from the Massachusetts Bay region and from the offshore grounds between southern Nova Scotia and Georges Bank. Evidence of this is shown by the following data: Out of a total of only 196 cod tagged on Stellwagen Bank, in Massachusetts Bay, from 1923 to 1928, 1 fish was recaptured between Rhode Island and New Jersey during the fall of each of the years 1923, 1924, 1925, and 1928 (no cod were tagged in Massachusetts Bay in 1926 and only 10 in 1927), showing that there was a decided tendency for some of these fish to go southward each year.

That some of the cod living offshore migrate to or beyond Nantucket Shoals is shown by the following recapture records: 1 of the 263 cod which we tagged off Cape Sable in 1928 was retaken off Chatham, Mass. On Browns Bank, 1,100 cod were tagged in 1927–28; and of the 28 recaptures reported up to the end of 1929, 2 fish had crossed the deep channel to the south and west, for 1 of them was taken on Georges Bank and the other in South Channel. On the northeastern part of Georges Bank, about 150 miles from Nantucket Shoals, 1,598 cod were tagged from 1926 to 1928, of which only 12 were reported recaptured. But 3 of these, or one-fourth of the total, have been recorded from along the route to southern New England, as follows: 1 cod, tagged September 26, 1928, in about latitude 42° 00′ N., longitude 66° 22′ W., was retaken on October 20 about 100 miles to the westward, toward Nantucket Shoals; while another fish tagged on the same date and in the same locality was recaptured on the shoals in May, 1929; of the cod tagged on Georges Bank in August, 1926, 1 was recaptured off Rhode Island in April, 1927. Some cod were tagged off southern Nova Scotia by the Biological Board of Canada. Among the recaptures are several fish taken on Georges Bank and several taken off Rhode Island.

SUMMARY

The size of the summer population of adult or nearly adult cod on Nantucket Shoals from 1923 to 1928 might be roughly estimated at between 3,000,000 and 4,500,000 fish.

Immigrant fish and the young which grow up in the Nantucket Shoals region have been sufficient to keep up the population there by offsetting losses due to deaths and emigrations.

A large part of the cod fry which seek bottom on Nantucket Shoals appear to come from eggs deposited along the coast of Maine. But although fry may be plentiful on the shoals, it would seem that they contribute only in a small way in keeping up the local population, for relatively few 1 to 2 year old cod have been found there.

Indications are that the stock of cod on Nantucket Shoals is kept up chiefly by the immigration of young adult and near-adult fish. Recaptures of tagged fish have indicated that the region to the northward of Cape Cod contributes annually but a small number of adult cod to the Nantucket Shoals grounds. The South Channel grounds and the southwest part of Georges Bank appear to be a more probable source, for, although scarcely any cod were tagged there and we have no direct evidence, these grounds are adjacent to Nantucket Shoals and support a large stock of fish. Another indication that a large part of the Nantucket adult cod are derived from near-by regions and not from the northward is to be had from scale studies which have shown that the cod to the north of Cape Cod differ materially from those to the southward in the early growth of their scales (p. 110).

AGE AND RATE OF GROWTH OF COD, PARTICULARLY THOSE ON NANTUCKET SHOALS

On the present investigation we did not specialize in a study of the factors which cause fluctuations in growth other than the collections of water temperatures and observations on the cod's food. We were concerned, however, in determining the growth of the cod in various parts of its habitat along the New England coast and in doing this utilized three methods, namely, length frequencies, scales, and growth registered by recaptured tagged fish.

Many observations have been made, especially in European waters, on the age and rate of growth of cod. The majority of the records obtained cover only the first year of growth, because most of the collections have been of young fish that were obviously in their first year of life. Even up to the completion of the second year records are not lacking, but above this age data become fewer and fewer as the fish grow older.

There is no particular rate of growth nor any average size at a given age that will cover the cod for all parts of its range. Environmental conditions affect growth in some cases to a marked degree, for in general the cod in Europe appear to grow more slowly than off the coast of America, and growth evidently is more rapid in the southern part of the fish's range than in the northern.

There has been much discussion as to whether food or temperature is the more important in regulating the growth of fish and various experiments in this direction have been undertaken.

Fulton (1904, pp. 170–171) believed that temperature was of first importance because it acted directly on the metabolism of the fish and affected the rapidity of digestion. He pointed out in his experiments with cod, haddock, and other species that fish gave up feeding altogether when the water became very cold (less than 3.8° C.), because under such conditions the ferments upon which digestion depends acted slowly or not at all. Appetite waits on digestion, and the latter may be correlated with the metabolism in the tissues. Cod and haddock living in cold-water aquaria in the winter were sluggish and moved about very little, whereas fish kept in artificially heated aquaria were very active and had a good appetite. However, 3.8° C. does not mark a critical temperature below which all cod cease feeding, for in some of the regions where cod live the year around, as off Labrador, Greenland, Iceland, and on the Grand Bank, the temperature is below 3.8° C. most of the time. Jensen (1926, p. 91), fishing for cod (*Gadus callarias*) off the west coast of Greenland with hooks baited with frozen herring, caught virtually no fish during June, when the bottom temperature on Fyllas Bank ranged from 0.20° to 1.06° C., but made good catches early in July at temperatures of 0.87° to 1.68° C. and again the middle of the month at 2.09° to 2.74° C. and Hjort and Ruud (1929, p. 17) record that the *Michael Sars* found excellent hand-line fishing for cod on August 5, 1924, in latitude 63° 55′ N., longitude 53° W., in 67 meters, where the temperature was about 1.6° C. The cod had been feeding on shrimps, amphipods, crabs, and sand eels. Cod in this region, therefore, feed when the temperature is appreciably below 3° C.

Undoubtedly there is some correlation between temperature and the desire of the cod to take food, but we know comparatively little on this subject with respect to the various "races" of *Gadus callarias.* Certainly we could expect Labrador cod, living in a temperature of, say, −1° to +5° C. to behave differently than Nantucket cod living in a temperature of 2° to 15° C. Yet even the latter fish do not cease feeding in the winter when the temperature drops below 3° C.

Along the New England coast an examination of cod stomachs at different seasons has shown that more food is eaten in summer than in winter. This, of course, may be due as much to a falling off in the food supply as to a loss of appetite due to a low temperature, for in February, 1928, off Delaware Bay, we found that instead of the cod being on their regular feeding grounds in 4° to 5° C. water they were around and inside the bay feeding on sand eels (*Ammodytes*) in about 2° C. water.

Cutler (1918, p. 488) kept flounders and plaice in water of various temperatures, made observations on the scales, and concluded that the amount of food did not affect the production of summer and winter bands, but that the formation of wide sclerites (generally produced during rapid growth) was due to high water temperatures while low temperatures resulted in narrow ones.

Winge (1915, p. 18), in his work on cod scales, sums up the effects of temperature and food on the growth of the cod, as follows: "Everything seems to indicate that the rate of growth of the cod is highly dependent upon conditions of temperature in the water, although perhaps in the main indirectly through the effect of temperature upon the quantity of nourishment."

Some light is thrown on the effects of temperature in retarding or increasing the rate of growth of cod fry by observations made in Norwegian waters. Dannevig (1925, p. 7) cites a rearing experiment carried out by Capt. G. M. Dannevig in 1886. At that time newly hatched cod larvæ placed in a pond, grew from a length of 3 millimeters on April 26 to an average length of 10 millimeters by May 31. A second experiment of the same sort, but made later in the spring, was carried out near Arendal on May 25, 1909, where Dannevig (1919, p. 45; 1925, p. 8) released about 100,000 1 to 2 day old cod larvæ (4 millimeters long) in the station's rearing pond in water having a temperature of 9.5° C. The larvæ grew as follows: June 12 they averaged about 20.5 millimeters (2 fish); June 16, 27.5 millimeters (2 fish); and on June 18, 24.5 millimeters (8 fish). The temperature in the pond on June 16 was 20° to 21.4° C. and must have been considerably warmer than that which obtained during the experiment in 1886. This difference is reflected in the rate of growth, for whereas the cod in 1886 averaged only 10 millimeters in length at 35 days old (April 26 to May 31), those reared in warm water in 1909 had reached a length of about 25 millimeters in 25 to 26 days (May 23–24 to June 18). Although other factors, such as the food supply, may have had some influence in bringing about this difference in rate of growth, it seems obvious that temperature played the most important part.

H. Thompson (1926, p. 6) is inclined to believe that the amount of food more than temperature decides the rate of growth, although haddock and gadoids which he had under observation in aquaria had a lessened desire for food from January to March. He concluded that, in general, captive haddock living in water of about the same temperature as at sea but supplied with a regular diet grow about twice as fast as they would under natural conditions.

Duff (1929, p. 16), who studied Sable Island (Nova Scotia) cod, concluded that adult fish in this region reach their maximum rate of growth during May, June, and July, and their minimum during January and February.

Whether it be temperature or food that is the more important factor in bringing about fluctuations in the rate of growth of cod, it has been found that, according to the scales, a period of rapid and of slow growth occurs each year, alternating throughout the life of the fish.

EVIDENCE FROM LENGTH FREQUENCIES

The first attempts at determining the age of cod were based upon length frequencies. (Hjort, 1914, p. 121.) In discussing the length-frequency method of age determination, first applied to fish by Peterson (1892), it is pointed out by Dahl (1909, p. 759) that this method is workable as a rule only up to the third year. He says further (ibid.):

> The method in fact rests on the supposition, that the start in size which the fry of one year possesses compared to the fry resulting from next year's spawning, that this start in size is retained also during subsequent years.
>
> To a certain extent this holds good, where the spawning season is short, and where growth is uniform. But experience shows that a long spawning season, unequal growth in different years and different localities, besides active and passive migrations, combine to blot out the "annual groups" in most species after the lapse of very few years. After the lapse of even one year the single individuals of a year group could not in all cases be recognized as belonging to a certain group and after a lapse of a few years a recognition of the year classes even as groups became almost impossible.

It would seem that the cod falls in that category, which makes it difficult to determine age classes by the length-frequency method for the spawning season is long, the fry carry out passive and many of the adults active migrations, and there is a regional variation in the rate of growth. But in spite of these difficulties year classes up to the third, and in some cases even to the fifth, may be recognized, provided fair-sized samples of fish are measured from each locality that is selected for study.

In European waters Graham (1926, p. 24) found that North Sea cod fry averaged about 3.6 centimeters early in July, 4.8 centimeters early in August, and 7.9 centimeters late in September.

Dannevig (1925, p. 10) found the average size of cod seined near Arendal, Norway, on the Skagerrack, to be 8 to 12 centimeters in October. Fry of these sizes were placed in a rearing pond and attained a length of about 15 centimeters (6 inches) by the following April when presumably about 1 year old.

Off the east coast of Scotland, Fulton (1901, p. 227) found that cod hatched around April were 4½ inches long by November, 5¼ inches by December, and 5⅝ inches by January.

Off the east coast of England, Wallace (1923, p. 17) found that the lengths of yearling cod ranged from 3 to 7 centimeters (1⅕ to 2⅘ inches) in July and from 5 to 14 centimeters (2 to 5½ inches) in October, but the number of cod so taken were too few to form dependable modes.

In the Irish Sea, Johnstone et al. (1924, p. 8) report catches of young cod taken by a prawn trawler, as follows: August, 137 fish, 4 to 19 centimeters, average 8.1 centimeters (3.19 inches); October, 64 fish, 9 to 19 centimeters, average 13.56 centimeters (5.34 inches); November and December, 48 fish, 9 to 19 centimeters, average 14.23 centimeters, (5.60 inches).

Off the east coast of Iceland, where the bottom water temperature is around 0° C. a good part of the year and where cod live from the fry stage until they are several years old, they reach a length of about 7 to 8 centimeters (3 inches) in April when about 1 year old. But in the warmer water off the southern coast of Iceland and around the Faroes "the cod grow much more in their first year." (Schmidt, 1907, p. 16–17.)

Around the Faroes cod spawn from February to May, and by early June the fry are about 1 to 2 centimeters long; by August, 5 to 6 centimeters; and by the following May and June, at the age of 1 year, 9 to 22 centimeters, with an average of about 16 centimeters (6.3 inches). At the end of their second year they average about 30 to 35 centimeters (12 to 14 inches). (Strubberg, 1916, p. 80–84.)

In the Barents Sea cod 1¼ years old were found to average about 12 centimeters (4¾ inches) in length. (Hjort, 1914, p. 129.)

According to these results, European cod grow during their first year to a length of about 6 inches in the North Sea, 5 inches around the Faroes and southern Iceland, 3 inches off the east coast of Iceland, and 4 inches in the Barents Sea. Thus its growth is more rapid in the southern part of its range than in the northern.

Very few catches of cod fry numerous enough for rate-of-growth determinations by means of length frequencies have been made in American waters. Bigelow and Welsh (1924, p. 420–21) cite the 1½ to 3 inch fry caught by Earll (1880) off Cape Ann in June, and the experiment of Smith (1901, p. 307), who obtained records of growth from the survivors of about 2,000,000 newly hatched larvæ which were placed in a lagoon at Woods Hole on January 11. The fry were seined periodically and exhibited the following growth:

Table 35.—*Lengths of cod fry seined at Woods Hole, Mass*

Date	Extreme lengths, millimeters	Average length		Date	Extreme lengths, millimeters	Average length	
		Millimeters	Inches			Millimeters	Inches
Apr. 8	29–38	32.9	1.3	May 25	28–68	64	2.5
Apr. 25	34–49	40.0	1.6	June 6	71–76	75.5	3.0
May 13	35–51	42.8	1.7	June 20	73–77	75	3.0

In addition to these, other cod fry have been seined off Woods Hole during spring and summer collecting, and from time to time some of these were preserved and in this way became available for study. These specimens, together with others taken on Nantucket Shoals by the *Albatross II* with a small otter trawl, are listed in the table which follows:

Table 36.—*The lengths of cod fry less than 6 inches long taken in miscellaneous catches off southern Massachusetts, from 1913 to 1927*

Locality and date	Number of specimens	Range in size, millimeters	Average size		Locality and date	Number of specimens	Range in size, millimeters	Average size	
			Millimeters	Inches				Millimeters	Inches
Woods Hole region:					Woods Hole region—Contd.				
April, 1913	5	36–44	40	1.6	June, 1916	24	43–60	52	2.0
April, 1921	1	27	27	1.1	July, 1913	3	79–107	97	3.8
May, 1916	7	47–59	52	2.0	July, 1914	2	67–90	79	3.1
May, 1923	7	43–70	56	2.2	Nantucket Shoals region:				
May, 1924	14	38–43	40	1.6	June, 1927	17	61–117	85	3.3

These records give a general idea of the growth of cod fry off southern New England up to the age of about 6 months. At that time (in midsummer) they are about 3 to 4 inches long.

It is but natural that there should be considerable variation in the size of the fry taken in the same catch. Not only is there some difference in the rate of growth among the fry, but the long spawning season makes it possible to catch on the same date fish all of which are less than 1 year old but some of which are as much as 6 months older than others. Thus in July or August 3 and 9 month old cod may be taken together. As a rule, however, although there may be a wide difference between the extreme sizes in a large catch of cod fry, most of the fish are of a rather uniform size, indicating either that they were derived from eggs spawned in some definite area and at a particular time during the spawning season, or that fish of a size tend to school together.

It is unfortunate that no catches of cod fry adequate for length-frequency determinations have been recorded from southern Massachusetts for the fall or the winter. But the many specimens of cod about 5 to 7 inches long observed in the stomachs of fish caught on Nantucket Shoals in September and October indicate that the fry living in this region attain a length of about 7 to 8 inches long when approximately 1 year old.

The scarcity of cod between 10 and 15 inches long taken in our catches on Nantucket Shoals already has been commented upon. Length-frequency data for these sizes are therefore lacking for this region, but some idea of the rate of growth of 1 to 2 year old southern Massachusetts cod might be had from a catch that was observed on Georges Bank. (Fig. 28.) These fish were taken in September and had a well-defined mode at 30 centimeters (about 12 inches). Their scales showed but one annulus, with a wide periphery of summer growth, so they were probably about 1½ to 1¾ years old.

If these fish are of the usual size attained by 1½ to 1¾ year old cod on the offshore grounds in the Gulf of Maine and if the rate of growth of the fish on Nantucket Shoals does not differ materially from this, then we might expect cod in the latter region to be about 14 to 15 inches long by the time they are 2 years of age.

Data on the growth of cod 2 years or more of age have been obtained from the length-frequency distributions of cod caught throughout our fish-tagging operations. Graphs dealing with these fish have already been given (figs. 15 to 24) in discussing the stock of fish on Nantucket Shoals. From these certain groups of fish have been selected to show rate of growth and are presented in the table which follows. The mean length of the cod in each group was calculated by selecting arbitrarily as many inch classes (usually three or four) as can be identified with a mode. For example, the average size of the *B* group of July 13–17, 1924 (fig. 16, No. 1), was calculated to be 23.9 inches by obtaining the weighted mean of the 23, 24, and 25 inch fish. This method must admit of some degree of error in locating the modal length of each group, but this is unavoidable because it is impossible to obtain the true mean length of the fish included in a "dominant group," as the limits of such a group are in this case unknown. But even if these limits were known, they probably would alter the calculated length but little.

The value of these calculations depends largely on whether or not we are dealing for the most part with fish from the same population. That we are doing so is suggested by the ease with which the dominant groups *A* to *D* (fig. 24) can be identified from the time they were first found on Nantucket Shoals until they passed out of the picture there. Furthermore, in spite of certain unknown factors that must of necessity be involved in a calculation of this sort, the data have an unusual degree of reliability because they include the records of thousands of cod living under natural conditions during all seasons.

TABLE 37.—*Rate of growth of cod caught on Nantucket Shoals from 1924 to 1928, as determined from length frequencies*

Symbols on figs. 16 to 23	Average date of capture	Average length of dominant size group	Average date of capture	Average length of dominant size group	Increase in length, inches	Time interval in days	Rate of growth per month of 30 days
B	July 14, 1924	23.9	Sept. 10, 1924	24.6	0.7	58	0.35
B	Sept. 10, 1924	24.6	May 6, 1925	25.6	1.0	239	.15
C	May 6, 1925	19.0	June 9, 1925	19.0	.0	34	.00
C	June 9, 1925	19.0	Aug. 23, 1925	20.2	1.2	75	.50
C	Aug. 23, 1925	20.2	Oct. 8, 1925	21.3	1.1	46	.70
C	Oct. 8, 1925	21.3	Sept. 8, 1926	24.4	3.1	335	.30
D	do	15.1	do	18.3	3.2	335	.30
D	Sept. 8, 1926	18.3	May 5, 1927	20.4	2.1	239	.25
D	May 5, 1927	20.4	June 20, 1927	21.0	.6	46	.40
D	June 20, 1927	21.0	Sept. 1, 1927	21.5	.5	73	.20
D	Sept. 1, 1927	21.5	July 17, 1928	24.0	2.5	319	.25

It was interesting to find, as might be expected, that there was a seasonal difference in the rate of growth. Thus in Table 37 the fish included in the two spring records (0.00 and 0.40) averaged 0.20 inch of growth per month, in the four summer records (0.35, 0.50, 0.70, 0.20) 0.44 inch, in the two fall to spring records (0.15, 0.25) 0.20 inch, and in the three records which embraced nearly a year's time (0.30, 0.30, 0.25) 0.28 inch. Accordingly, these Nantucket Shoals cod made their slowest growth from the fall to spring and their fastest during the summer.

At an average rate of growth of 0.28 inch per month the growth per year would be about 3.4 inches. Making allowances for somewhat faster and slower growth, it might be said that, based on the length-frequency method of determination, cod from about 15 to 26 inches long living on Nantucket Shoals increase in length about 2½ to 4 inches a year.

EVIDENCE FROM TAGGED FISH

Our records of growth made by recaptured tagged cod have yielded perhaps the most dependable information, for they are based more on fact than on theory. Of course some degree of error may obtain even here, for we can not be sure that in all cases the growth of a tagged fish was the same as it would have been if the fish had never been tagged. The suppuration which often occurs around the point where the tag is attached to a fish has already been described. It is probable that in a case of excessive irritation normal growth is curtailed; in fact, we have a few instances where cod recaptured a year or so after tagging, in poor condition, had gained scarcely anything in length. But eliminating such records from our calculations and considering only the fish that were in reasonably good to fine condition when recaptured, we are justified in accepting the growths as being almost the same as they would have been if the fish had not been tagged.

The growth records of tagged cod obtained by the tagging vessels *Halcyon* and *Albatross II* and those furnished by fishermen were at first separated in order to determine whether the results varied appreciably, for while all of our recaptures were measured by the same standard and usually by the same person, those of the fishermen may have been measured by a number of different methods. It was found, however, that the two groups of data agreed very well, and, therefore, the records were combined in the table which follows. About one half of these remeasurements were made on Nantucket Shoals by the tagging vessels, while the half which came from fishermen were from fish nearly all of which were recaptured between Rhode Island and Delaware.

TABLE 38.—*Increase in growth registered by Nantucket Shoals cod between the time of tagging and recapture*

Lengths of fish in inches at time of tagging	Number of fish	Average time in months from date of tagging that fish were recaptured	Average increase per month in inches
17 to 20	28	8.4	0.32
21 to 24	58	5.3	.33
25 to 28	54	5.8	.21
29 to 32	35	6.7	.22
33 to 35	6	7.7	.19

The average time of recapture from the date of tagging, given in Table 38, includes many records of fish caught after they had been at liberty only one to three months, but these are balanced by other recaptures made as much as 20 to 24 months later. The average increase per month was obtained from each individual recapture record. Thus, a fish recaptured after two months showing a gain in length of 0.50 inch would be classed at a rate of 0.25 inch per month, as would also a fish taken 12 months later showing an increase of 3 inches.

We are justified in using the increase in length per month to calculate the increase per year because cod recaptured after they had been at liberty for more than one year had not grown at a rate appreciably different from those which had been at liberty only a few months. Data on the 12 to 24 month fish are as follows: Fish 17 to 20 inches long at the time of tagging grew 0.29 inch per month (8 fish); 21 to 24 inch fish, 0.30 inch (10 fish); 25 to 28 inch fish, 0.22 inch (9 fish); 29 to 32 inch fish, 0.25 inch (8 fish); and the 33 to 35 inch fish, 0.19 inch (2 fish).

Among the individual records of fish taken long after tagging are the following: A 28-inch cod gained 5 inches in 18 months; a 26¼-inch cod gained 5.25 inches; a 16¾-inch fish gained 6.25 inches in 20 months; a 16½-inch cod gained 11¼ inches in 24 months; and a 23½-inch cod gained 3 inches in 37 months. This latter fish was in poor condition and its growth was considerably below normal. It was not included in Table 38.

An attempt was made to detect a difference in growth between winter and summer by segregating the recaptured and remeasured cod into two groups. But as none of the fish fell wholly within the winter season, no marked difference in the rate of growth was noted between those fish tagged in the fall (September–October) and recaptured in the spring (April–May) and those tagged in the spring and recaptured in the fall, possibly because in each instance there was a fast and a slow growing period which balanced each other. A seasonal difference in the rate of growth was more evident from our length-frequency data.

According to the growth registered by tagged fish, Nantucket cod 17 to 24 inches long increase in length about 4 inches a year, while fish 25 to 35 inches long increase about 2½ inches a year. These size segregations were made arbitrarily, for it is obvious that there is not a sharp demarcation between the two groups, and as the fish become older there is a gradual decrease in the gain in length that occurs each year.

Increases in growth registered by recaptured tagged fish were very much the same in European waters as off our own coast.

Gains in length shown by the cod tagged in Scottish waters by Fulton (1889–1892) amounted to about one-fourth to one-half inch in several months for fish ranging in length from 14 to 25 inches. The greatest increase was that made by a 15½-inch cod which measured 18 inches about seven months later (Fulton, 1893, p. 190). Fulton believed that the abrasion caused by the tag retarded natural growth. (Ibid., p. 177.)

Schmidt (1907, p. 17) obtained only four dependable remeasurements from recaptured cod as a result of the tagging around Iceland in 1904 and 1905. These fish, about 20 to 24 inches long when tagged, increased about 2½ inches a year. Later tagging experiments done in Faxa Bay, on the southwest coast of Iceland, showed that 8 of the cod (40 to 66 centimeters long when marked), recaptured 10 to 14 months later, had increased in length about 18 centimeters (7 inches) per year. This was a more rapid rate of growth than was found on the north and east coasts of Iceland, where the water is colder. (Saemundsson, 1913, p. 30.)

Three cod (38 to 43 centimeters) tagged off the Faroes in August and recaptured in May, nine months later, had increased in length about 12 centimeters. (Winge, 1915, p. 13.) In Danish waters some lots of tagged cod (35 to 57 centimeters) increased about 12 centimeters (4½ inches) during the first year after marking, while others (45 to 65 centimeters) increased only 7 to 9 centimeters. (Strubberg, 1922, p. 33.)

According to these few records obtained from recaptured tagged cod, fish from about 14 to 25 inches long grew about 1½ to 3 inches in length during one year off the east coast of Scotland, 3 to 4½ inches in Danish waters, and as much as 6 to 7 inches off the Faroes and the southwest coast of Iceland. The latter appears to be much too high, especially when it was found that fry living around the Faroes and southern Iceland grew more slowly than those living in the North Sea (p. 99). The data on which these records are based are very meager, and, as Saemundsson (1913, p. 30) says, with respect to the Icelandic fish, they should be accepted with caution. If reliable remeasurements had been obtained from a large number of recaptured tagged fish instead of but few it is probable that cod ranging in length from 14 to 26 inches, living in the North Sea, would show an average increase of about 3 inches a year, with the smaller fish gaining somewhat more than the larger; in other words, very much the same rate of growth as was found for southern New England cod.

EVIDENCE FROM SCALE STUDIES

No attempt will be made here to give a detailed account of the studies that have been made on fish scales. This has been well covered by such authors as Thomson (1904), Dahl (1909), Taylor (1916), Lee (1920), Van Oosten (1929), and Graham (1929b). Growth of the cod's scale has been described by Cunningham (1905) and Winge (1915) and scales in general by Paget (1920) and Creaser (1926).

In this paper I have compared the growth and age of the cod according to its scales with that shown by length frequencies and the actual growth made by marked fish. Data are also presented concerning the zones of growth laid down on the scales, particularly the first growth zone and its significance in throwing light on the migrations of the cod.

The scales of cod afford perhaps the most ready means for determining age and rate of growth. Up to the sixth or seventh year they are reasonably dependable, but beyond this age they become increasingly difficult to interpret. Occasionally a very old fish has remarkably well-defined scales, and such fish assist in placing the more doubtful ones in their approximate year class.

Not only has the scale method of age determination for the cod been verified by tagged fish, but scales have been compared with otoliths and skeletal structures. Winge (1915, p. 19) found that the number of growth zones laid down on the otoliths agreed very well with the number of winter or slow-growing zones on the scale. The oldest cod examined by Winge was 13½ years old according to its scales, compared with a determination of about 14½ years according to its otoliths. Cunningham (1905, pp. 137–139), working with rather young cod, found that the number of annual zones laid down on the scales and on the otoliths was the same. He also utilized the pectoral girdle and the vertebræ, but found these skeletal structures to be untrustworthy as a means of determining age. Saemundsson (1923, p. 6–7) used otoliths, the coracoid, and the pelvic bone in determining the age of Icelandic cod and was able to check the age of comparatively young otoliths with the scales. Graham (1929a, Pt. I, p. 42) concludes that by using the precise method of making scale tracings (Graham, 1926) the majority of cod scales will give a correct age reading. He found, too, that otoliths showed some degree of correspondence with the scales.

Typical cod scales under magnification somewhat resemble a thumb print. They are usually oval in shape and are marked with concentric rings, or circuli, the first one of which is generally offcenter, away from the pigmented part of the scale. The numerous circuli form growth zones, each of which, with the exception of possibly the first growth zone which may have all its circuli about equally spaced, is divided into two parts—one composed of widely spaced circuli, the result of rapid growth, and the other of closely spaced circuli formed during a period of relatively slower growth. (Fig. 29.) The wide and the narrow circuli in each zone, when taken together, are believed to mark about one year of growth. Winge (1915, p. 10, figs. *5a* and *5b*) shows by means of tagged Faroe cod, which were recaptured one to two years later, that a "minimum," or annulus, is formed during the winter. That one annulus forms each year has been found on the present investigation, too, for those tagged fish recaptured a year later had the additional year of growth registered on their scales. (Fig. 30.)

It is the seasonal variation in growth registered on the scales that permits the age of the fish to be calculated by this means. And as there may be regional differences in growth dependent upon the physical and biological conditions of the fish's immediate environment, each cod region that differs appreciably from another in temperature, food supply, etc., offers a separate problem with respect to the interpretation of the growth zones on the scales.

Winge (1915, p. 12) found that cod from the Faroes grew more rapidly and laid down widely spaced circuli on their scales in summer and closely spaced circuli in winter. It was his opinion that cod in other localities probably do the same. Saemundsson (1923, p. 27), who worked with the cod around Iceland, found, according to the scales and otoliths, that the most rapid growth took place on the south coast, with a gradual decrease as one goes to the right around the island. The slowest growth was found on the east coast. At Arendal, Norway, Dannevig (1925, p. 21), who experimented with young cod in a rearing pond which had very much the same characteristics as the sea which it adjoined, raised some of the fry to an age of 2½ years

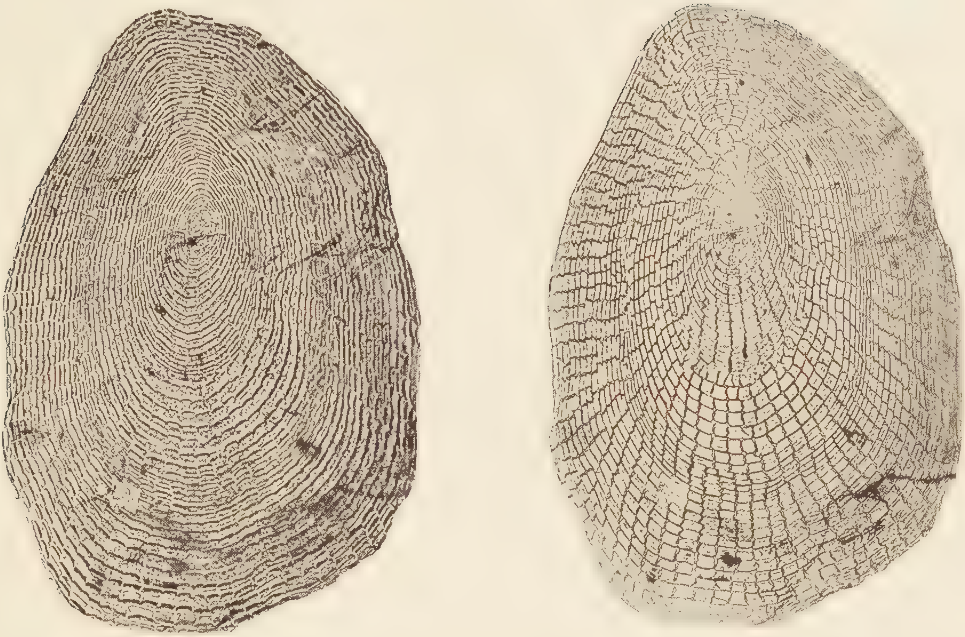

Figure 29.—Scale of a cod 17 inches long, in its third year, showing narrow and wide circuli. The scale on the left is focused to accentuate the ridges of the platelets, or sclerites, while the one on the right is focused to show the basal parts

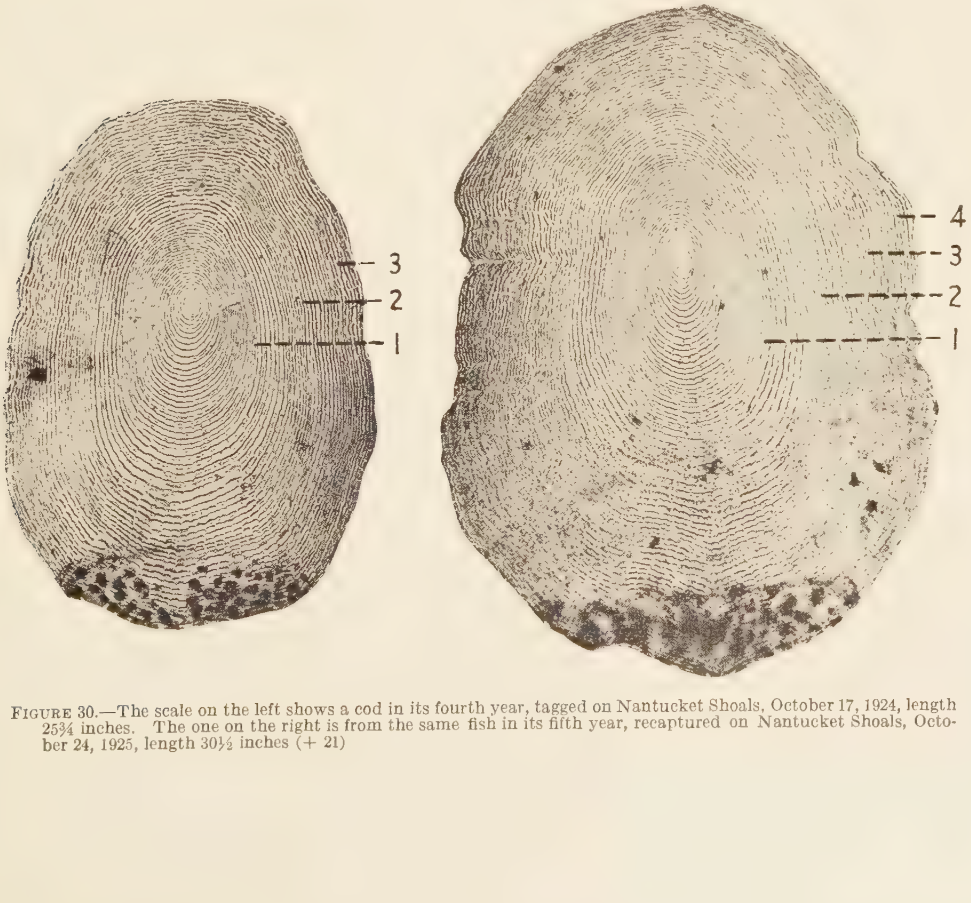

Figure 30.—The scale on the left shows a cod in its fourth year, tagged on Nantucket Shoals, October 17, 1924, length 25¾ inches. The one on the right is from the same fish in its fifth year, recaptured on Nantucket Shoals, October 24, 1925, length 30½ inches (+ 21)

He found that the formation of the closely spaced circuli took place in the late summer or autumn and the widely spaced circuli during the winter. Because of this, he states that the term "winter zone" should be abandoned and suggests using "zones of minimum sclerites, or resting zones." Dannevig intimates, however (ibid., p. 22), that scales taken from cod living under natural conditions might have produced different results. Duff (1929, p. 11), who studied the peripheral circuli of cod 50 to 55 centimeters long caught on the Sable Island Banks (Nova Scotia), found that the zone of broad circuli was formed on the scales from March to July, inclusive, and most of the narrow circuli from August to December. Such few circuli as formed during January and February were narrow.

Ordinarily the widely spaced circuli on the scales of southern New England cod are laid down from April to September or October and the closely spaced circuli during the remainder of the year. Some of them, however, begin adding widely spaced circuli as early as February and March and the narrow circuli may start to form as early as August. Occasionally a fish is found that exhibits rapid scale growth during the winter as well as the summer. For example, a sample of 51 adult cod caught off Atlantic City, N. J., within the period from March 23 to April 2, 1928, showed the following peripheral growth on their scales: 39 fish had only closely spaced circuli; 11 fish had from 1 to 4 widely spaced circuli, indicating that more rapid growth had begun as early as February (if not January) and the beginning of March; while 1 fish had 6 very wide circuli, which appeared to represent a full year's (its fourth) growth.

In regions where food and temperature fluctuate widely we can expect, and often do find, that the scales are more sharply defined as to age than in regions where more stable conditions obtain. J. S. Thomson (1904, p. 99) made observations on a whiting (*Gadus merlangus*) from the time it was a month or so old (10 to 20 millimeters) in May, 1902, until it died in July, 1903, and was 8½ inches long. The fish had been fed regularly during this time and the water temperature in the aquarium was fairly constant, although there was a marked difference between summer and winter. Upon examination the scales of this fish showed uniform growth, without distinct areas of summer and winter growth such as was registered on scales of other young whiting taken from the sea. Thomson believed, therefore, that it is variation in food supply rather than variation in temperature which influences metabolism and indirectly brings about the formation of annual rings on scales. Mention has already been made of H. Thompson's experiments (1926, p. 4), showing increase in growth due to an ample food supply; of Fulton's experiment (1904, p. 162), showing that a low water temperature retards feeding and, as he suggests, growth; and of Cutler's experiment (1918, p. 488), from which he concludes that temperature and not food caused the summer and winter bands on the scales of flounders.

Winge (1915, p. 13) throws some light on the rôle which the environment plays in the spacing of the circuli on the cod's scales. Three of his cod which had been tagged August 16, 1911, off the Faroes (about 15, 16, and 17 inches long), were recaptured on the same ground, two on May 17 and one on May 25, 1912. Scale samples had been taken at the time of tagging and again when the fish were recaptured nine months later. As the fish were recaptured in the same place where they had been tagged, it was assumed that they had not migrated away and had lived together under the same conditions during that time. Winge plotted curves showing the distance between the circuli, utilizing five scales for each fish. Not only did each of the five scales from the same fish exhibit the same fluctuations but the scales for all three fish showed that they had responded in the same way to environmental conditions between the time of tagging and recapture and also for some time previous to then. A mean growth curve of the five scales examined from each of these fish is given in Figure 31, in which the broken line *A* sets off the growth of the scales for a time preceding the capture of the fish on August 16, 1911, and *B* the growth between then and May 17 to 25, 1912. The scale of another cod recaptured 6 to 8 miles away from the three fish just mentioned showed different fluctuations in growth.

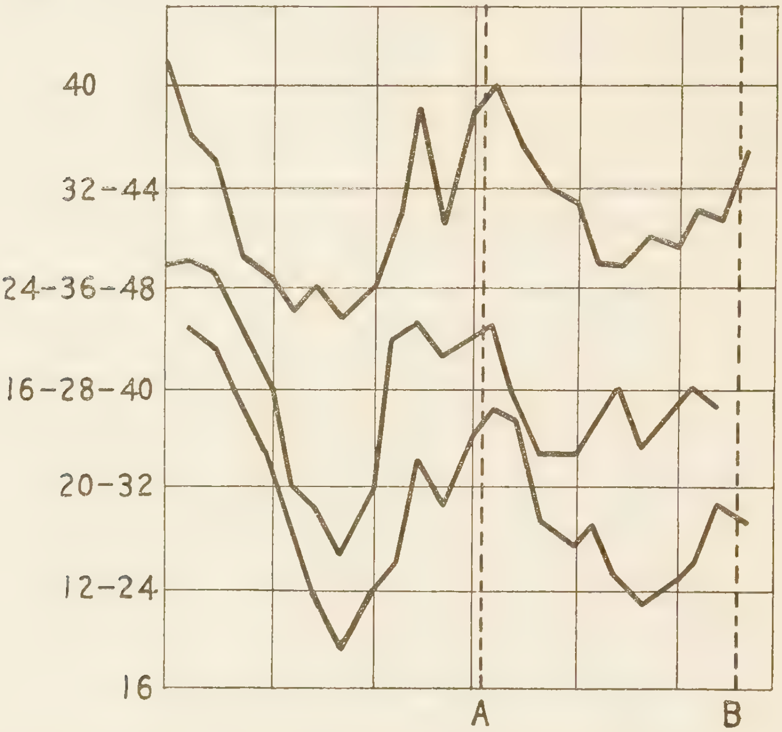

FIGURE 31.—"Mean scale" curves for three companion cod taken off the Faroes. *A*, at the time of first capture, August 16, 1911; *B*, at the time of second capture, May 17–25, 1912. (After Winge)

Winge's results, just cited, throw so much light on the question of growth, as registered on the scales of the cod according to the response of the fish to its environment, that I have examined scales from New England tagged cod in order to see whether they, too, would exhibit this result.

The scales were studied of several cod that had been tagged together and which were recaptured in the same locality more than a year later. Fish of about the same size were selected. Starting from the focus and running along a radius extending to the periphery, the distance between the circuli was measured under rather high magnification and the results were arranged graphically. But in none of the six or eight fish examined was I able to get such a clear-cut agreement in the fluctuations of growth as was obtained by Winge. For example, a comparison was made of the scales of 2 Nantucket cod tagged May 6, 1927, and recaptured by the *Albatross II* July 19, 1928. These fish were 18½ and 19½ inches long, respectively, on the former date and both of them were 22 inches long on the latter. Although these cod had very likely lived in close association for over a year, one of them gained 1 inch more in length than the other; and, although each of them had added an annulus to its scales, the minor fluctuations in growth, circulus compared with circulus, did not appear to correspond.

The first zone of growth on the cod's scales presents difficulties, for it is often hard to calculate whether it represents the first full year of growth or only part of a year. Scales first appear when cod fry are about 1½ inches (38 millimeters) long, about six to eight weeks after hatching and at about the time they take to the bottom. As cod larvæ hatch from fall to late spring, it is possible that the formation of the first "annulus" might be completed on the scales of some fish when they are only 6 or 8 months old, while others may be as old as 12 or 14 months.

It is assumed that the widely spaced circuli which marks the beginning of the second year's growth begin to form the first spring following the fall to spring that the fish was hatched. The demarcation between the first annulus and beginning of the second zone of growth is generally sharp on the scales of cod living off our coast, but is not so clear on the scales of some European fish. Graham (1926, p. 346), studying North Sea cod, measured the distance between circuli on the cod scale very much as did Winge (1915) in order to determine the limit of the first "winter" zone. He gives his technique (ibid., p. 351) as follows:

> The width of the narrowest pair of adjacent sclerites in the innermost suspected narrow zone is taken on dividers and fitted to the width of the widest sclerite in the adjacent wide zone outside it. If the dividers fall within it the narrow zone is the first "winter" ring. If they span or straddle the wide sclerite the criterion rejects the suspected narrow zone.

Graham did his measuring directly on the projected scale, magnified about 100 diameters. While this method apparently is helpful in identifying a secondary minimum within the first zone of growth, it, of course, can not determine whether the 15 or 20 circuli within the first zone represents 6, 8, or 12 months of growth.

While the trend of growth should be the same on all typical scales found on the same fish, there is considerable variation in the number of circuli, depending on what part of the body the scale is found, as already pointed out by various investigators. The small scales along the back, near the head, or on the belly do not have as many circuli as the large scales along the side. And even two scales lying almost side by side may vary somewhat in the number of their circuli. For example, Winge (1915, p. 6) found on a fish with two distinct minima on all of its scales that a large scale from between the lateral line and the second dorsal had 48 circuli, a scale from the base of the pectoral had 45, and a scale from the dorsal area, obliquely in the rear of the eyes, had 32. Because of this variation, it is difficult to compare the fluctuations in growth as between two scales from the same fish or between scales from two fish of about the same size, living together, unless comparable scales having about the same number of circuli are selected.

In order to gain some idea of the average number of circuli that form on the scales of southern Massachusetts cod during their first full year of growth, the scales of fish less than a year old were examined, with the following result:

TABLE 39.—*Number of circuli on the scales in relation to length of juvenile fish*

Number of specimens	Length	Range in number of circuli	Average number of circuli	Number of specimens	Length	Range in number of circuli	Average number of circuli
	Millimeters				*Millimeters*		
1	21–30			4	71–80	5–8	6.1
2	31–40	1	1.0	8	81–90	5–13	7.5
7	41–50	1–4	1.7	5	91–100	6–9	7.8
9	51–60	1–6	3.4	1	101–110	9–11	10.0
6	61–70	2–8	5.0	2	111–120	9–11	10.0

These tiny scales were sampled by scraping a scapel along the side of a specimen and wiping on a slide. By so doing, scales were taken from a large part of the body and they included the smaller ones along the back and near the median line of the belly as well as the larger ones along the middle of the side. The smaller scales had fewer circuli than the larger, so that the count obtained from any one fish might run from 2 to 5, 4 to 6, 5 to 8, etc. A variation of this sort is shown by Meek (1916, p. 219), who records cod of about 5.8 centimeters taken in July, with 0 to 2 circuli; and in October, fish 6.9 centimeters long with 2 to 4 circuli, and fish 11.1 centimeters with 7 to 9 circuli on their scales.

The fish listed in Table 39 were taken during several collecting years. In general, the smaller ones were caught in April and May and the larger in June and July. Accordingly, southern Massachusetts cod 4 or 5 inches long in the summer have about 8 to 12 circuli on their scales. Such fish are less than 1 year old, so that by the time a full year has been completed the number of circuli should be appreciably greater than 12. Young cod caught between Cape Cod and eastern Maine had nearly the same circulus count, with respect to their size, as did the southern Massachusetts cod, but as we had only 17 young fish from Maine (50 to 120 millimeters long) taken not from April to July but from August to September, a fair comparison could not be made.

Five cod caught on Nantucket Shoals in October, selected at random, had the following circulus count on their scales: Length of fish 156 millimeters, scale circuli 21 to 22; 168 millimeters, 21; 171 millimeters, 21; 189 millimeters, 21; 197 millimeters, 19 to 21. All these scales had only one zone of growth, but as they were caught well into the fall they probably were nearly 1 year old. Another specimen 178 millimeters long, taken with the above ones, had 13 closely spaced circuli in the first zone of scale growth, followed by 5 widely spaced circuli. This fish apparently hatched in a different season than the others.

It is not understood why the 156 millimeters cod had as many circuli as the 198 millimeter fish, for whether they were the same age, with one growing faster than the other, or whether they grew at the same rate, with one being older than the other, one might expect the larger fish to have the more circuli on its scales.

According to the scale growth of the few 156 to 197 millimeters cod, presumably nearly 1 year old, taken off southern Massachusetts, we could expect that cod living in this region, from the fry to adult stage, should have about 20 to 22 circuli on their scales within the first zone at the end of about one complete year of growth. To determine this, the scales of adult Nantucket cod were examined. The first growth zone on some of these scales, no doubt, represented somewhat less than a full year's growth and on others somewhat more, but, as a large sample was utilized, the average must have been just about between.

TABLE 40.—*The number of circuli formed on the scales of Nantucket Shoals cod within the first zone of growth (presumably the first year's growth), segregated according to the size of the fish*

Length of fish, inches	Number of fish	Average number of circuli in first zone of growth	Length of fish, inches	Number of fish	Average number of circuli in first zone of growth
20	6	22.0	31	17	19.9
21	4	18.5	32	17	18.8
22	11	20.4	33	2	18.0
23	12	19.0	34	5	21.2
24	19	20.3	35	5	21.6
25	35	19.7	36	8	18.9
26	66	19.7	37	----------	----------
27	79	20.1	38	4	19.0
28	63	20.8			
29	55	20.9	Total	438	20.2
30	30	20.7			

As the scales of this sample of adult Nantucket Shoals cod had an average of about 20 circuli in the first growth zone of their scales, or about the same number as the 156 to 197 millimeters yearling cod just mentioned, it is evident that approximately this number is formed when the fish have completed their first year. Therefore when the first growth zone contains relatively few circuli, say 10 to 15, it is apparent that these represent less than one year's growth, and when the number is large, say over 25, it is probable that they are the result of more than one year's growth.

One striking result brought out by the tabulation given in Table 40 is that the average number of circuli in the first growth zone on the scale is about the same. regardless of whether the fish were as small as 22 or 24 inches long or whether they were as large as 36 or 38. This is as it should be if we are to believe that cod do not shed their scales but retain them from the time they first form, throughout their lifetime. Regenerated scales which take the place of those which are lost (through injury) can always be easily detected by a central area without circuli, which often takes up about one-half of the entire scale. Creaser (1926) and Van Oosten (1929) have established experimentally the correctness of this interpretation of these central areas devoid of circuli.

Segregation of cod stocks as shown by scale structure.—Perhaps the greatest value to be obtained from a study of the first-zone circuli is the light which it throws on the origin and migrations of the cod, for it seems apparent that if the growth of the scales from two separated grounds should differ, then no general intermingling of the cod dwelling in the two regions in question will have occurred. The fact that Winge (1915, p. 15) found that cod living around the Faroe Islands usually form only about 12 circuli on their scales during their first year of life, much fewer than Nantucket cod, led to an examination of cod scales from various localities along the New England coast. The chief object of this was to determine whether there was a noticeable difference in the first-zone circulus count, on the average, between the cod living to the northward of Cape Cod and those living to the southward; and, if so, whether the difference was great enough and consistent enough to separate the New England cod into two or more great stocks of fish.

TABLE 41.—*The number of circuli formed within the first zone of growth on the scales of cod living north of Cape Cod compared with those living to the southward*

Locality	Date	Number of fish	Average length, inches	Average number of circuli within the first growth zone of scale
North of Cape Cod:				
Browns bank	September, 1928	21	23.1	15.8
Northeast Georges bank	January, 1924	53	38.2	13.9
Do	September, 1928	41	28.0	16.0
Mount Desert, Me	August, 1924	40	16.1	15.4
Do	August, 1928	35	18.7	16.9
Platts bank	April, 1927	35	26.0	14.9
Stellwagen bank	July, 1924	29	25.3	15.6
Do	October, 1925	44	22.6	14.9
Total		298		15.3
South of Cape Cod:				
South Channel	June, 1929	36	26.4	20.6
Nantucket Shoals	Summer, 1923	573	26.3	20.1
Do	Summer, 1927	32	22.5	19.0
Do	Summer, 1928	62	22.2	20.1
Cholera bank, N. Y	November, 1927	50	25.2	21.2
Do	November, 1928	36	23.9	21.3
Atlantic City, N. J	March, —— April, 1928	51	25.1	21.3
Total		840		20.5

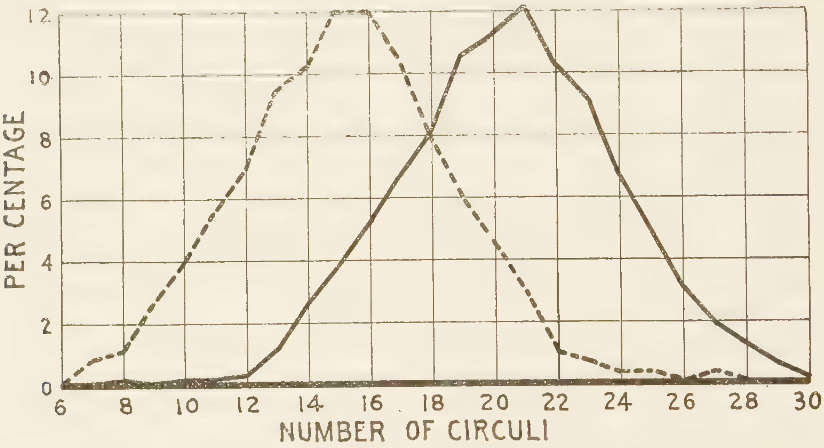

FIGURE 32.—Frequency-distribution of the number of circuli within the first zone of growth on the scales of the cod listed in Table 41. Broken line for the north of Cape Cod; solid line for the south of Cape Cod. Smoothed ounce by a 3-class moving average

There is unquestionably a significant difference in the count of the first-year scale circuli between the cod living north of Cape Cod and those living to the southward in the samples presented in Table 41. All these scale samples were selected at random, without respect to the size of the fish, so that small, medium, and large cod are included in almost every group of scales that was studied. Both the north of Cape Cod and the south of Cape Cod scales gave a simple mode in the frequency distribution of the first-year circulus count, as shown in Figure 32.

Regardless of what may have caused this marked difference (whether differences in the rate of growth or in the time of spawning), the fact that it exists indicates that the stocks of cod living north and east of Cape Cod are for the most part distinct from those living to the southward in that the fish from the two regions do not intermingle in a large way.

This conclusion is supported by the results of our tagging both to the north and the south of Cape Cod and was much the same conclusion arrived at by Smith some 25 years before (p. 8), when he found that none of his cod were reported recaptured to the northward of Cape Cod.

As most of the cod given in Table 41 averaged from 22 to 28 inches long and were from 3 to 5 years old, it is apparent that up until that age most of them remained in the general vicinity of the region where they first took to the bottom as fry. If this were not the case and if there were an extensive intermigration of cod between Nantucket Shoals and grounds to the northward, then we could expect very little difference in the count of first-year circuli between the fish living to the northward of Cape Cod and those living to the southward.

No scale samples were obtained from cod living in the western part of Georges Bank, intermediate between the northeastern part of the bank and the Nantucket-South Channel region, so we do not know if the fish from there have a first growth-zone circulus count that falls somewhere between 15 and 20. But a sample of scales taken from 45 cod caught May 3, 1927, on the Chatham grounds 13 miles northeast of the most northern tagging ground on Nantucket Shoals had an average of 18.1 first-zone circuli, which number falls between the averages of 14.9–15.6 obtained on Stellwagen Bank and the 19–20.6 found in the Nantucket-South Channel region.[17]

The fact that the scales of cod caught on the Cholera Bank near New York City and off Atlantic City, N. J., agree in circulus count with those from the Nantucket Shoals region and disagree with those from the north and east of Cape Cod is significant, for we have here further proof that the grounds off southern New England supply a large part of the cod which migrate each winter to the Rhode Island-North Carolina region.

Beyond the first growth zone the differences in scale circulus count between the cod living north of Cape Cod and those to the southward tend to disappear, so that from the third year on the count is virtually the same for both groups of fish.

Age and rate of growth of cod as determined from their scales.—Lea's (1910) method of determining the annual growth[18] of fish by means of their scales has been used by various investigators with more or less success. It was based on the supposition that the scales and body of a fish grow at proportionately the same rate, at least nearly enough so that the lengths calculated for each year of life would be essentially correct. Other investigators using this method have found that, although it is workable, corrective factors must be established for each species because, as Lee (1920, p. 21) points out, the ratio of length of the scale to the length of the fish changes with age.

Thompson (1923, p. 75) points out in the case of the haddock that the scales first appear along the flank of the body and then only when the fish has reached about 3 centimeters in length and that the size of the first platelet is proportionately smaller than that of the fish, so that about a half centimeter must be added to the calculated first-year size. Scales which appear later on other parts of the body may increase this error to as much as 2½ centimeters. Cod scales, too, appear when the fry is about 3 centimeters long, and the first ones are found along the sides of the body.

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[17] The South Channel scales were obtained from fish caught on the extreme western edge of South Channel in about longitude 69° 24′ W., latitude 41° 17′ N., which is to the southward of the Chatham grounds and which might, in fact, be termed the eastern edge of Nantucket Shoals.

[18] Annual growth is calculated by measuring the growth zones along any convenient radius on the scale and comparing each zone with the total length of the radius selected and the total length of the fish.

Winge (1915, p. 11), working with the cod, concluded that there was a close agreement between the growth of the scales and that of the fish. He selected 7 scales from each of 4 fish (31 to 43 centimeters long) at the time of tagging and again 1 to 2 years later, when these fish were recaptured (when 43 to 66 centimeters long.) As a result he found that each of the scales examined from the same fish increased in size in approximately the same proportion and that in each case the "increments of growth in scale and cod, respectively, are very nearly directly proportional." However, Huntsman (1919, pp. 65–66) points out that the scales of Winge's smallest cod had grown somewhat faster than the fish, while the scales of the larger cod had grown proportionately less than the fish, and states that "these results indicate a definite change in the growth of the scale relative to the growth of the fish, namely, an early more rapid and a later less rapid growth. This is similar to what I have found for other fish by a different method." Huntsman (1918a) discusses the errors resulting from calculating lengths from the annuli formed on the scales and describes a method for reducing the degree of error. Duff (1929, p. 10) concurs with Huntsman's views, for he found that the rate of growth of the cod and its scales are not equal but vary throughout the year, and that the scales of small fish were longer in proportion to the length of the fish than the scales of large cod.

Lee (1912, p. 15) found that on herring and haddock scales the calculated lengths attained at 1 year of age were larger for the younger fish than for the older. For example, the scales from one lot of haddock made it appear that on their first birthday the 2-year-old fish averaged 18.3 centimeters; the 3-year fish, 17.6 centimeters; the 4-year fish, 16.6 centimeters; and the 5-year fish, 15.1 centimeters. This same progressive decline obtained for the second and succeeding years, making it seem that with increasing age the fish showed a decreasing rate of growth in the calculated values for each year of their lives. This is called by Lee "the phenomenon of apparent change in the growth rate." Thompson (1923, p. 15) concurs with the findings of Lee in regard to the haddock, for he found that while there was little error if 1+-year old haddock were used in calculating the size attained at 1 year of age the error increased as the scales from older fish were examined.

Whether the rate of growth calculated from cod scales will show a progressive decrease, as was found with the scales of haddock and certain other fish, is not definitely known at present. According to the sample of scales given in Table 42, there appears to be a slight tendency of this sort which, although not shown by the averages, manifests itself in the 6, 7, and 8 inch values of the III, IV, and V year classes.

TABLE 42.—*Length attained at the completion of the first growth zone as calculated from the scales of Nantucket Shoals cod of various ages caught during the summer of 1923*

Age of scale	Calculated length in inches at completion of first growth zone												
	3	4	5	6	7	8	9	10	11	12	13	Total	Average
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Inches*
II					5	8	1	1				15	7.86
III	3	5	16	17	29	19	9	4	5			107	6.93
IV	1	8	28	81	100	65	23	21	10	1	1	339	7.18
V		2	11	22	15	6	8	10	3			77	7.18
VI			2	4	3	7		4	1	1		22	7.91
VII			1		3	1	2		1			8	7.87
VIII			1						1			2	8.00
IX			1	2								3	5.66

The number of fish included in the III, IV, and V year classes in this table appear to be sufficient to give a good idea of the frequency distribution of lengths at the completion of the first growth zone for this particular sample of fish. Thus the III and the IV year olds present simple modes at 7 inches, while the V-year fish have two modes, at 6 and at 10 inches, respectively. This does not necessarily imply that the V-year fish during their first year of life were divided into slow-growing and fast-growing groups. What is more probable, the fish may have originated from different spawning periods, for the 6-inch fish might have come from eggs deposited late in winter, while the 10-inch fish could have hatched early in the winter. If this were so the difference in the calculated first-year size (between 6 and 10 inches) could be due largely to a difference in age and not to rate of growth.

The rôle of the circulus count in defining the first full year of growth already has been discussed.

In order to show the relation between the calculated lengths at the end of the first year and the number of circuli formed in the first growth zone, most of the III, IV, and V year scales included in the preceding table have been arranged in Table 43 according to number of first-zone circuli.

TABLE 43.—*Relation between number of first-zone circuli and calculated length at the formation of the first annulus*

Circuli in first zone	Average length, in inches, calculated from first growth zone	Fish	Circuli in first zone	Average length, in inches, calculated from first growth zone	Fish	Circuli in first zone	Average length, in inches, calculated from first growth zone	Fish
8–9	3.3	1	16–17	6.0	56	24–25	7.8	58
10–11	5.1	1	18–19	6.2	94	26–27	9.2	19
12–13	4.3	4	20–21	7.0	123	28–29	10.0	5
14–15	5.5	39	22–23	7.4	103			

It is significant that the calculated lengths of fish with 20 to 21 circuli in the first-growth zone of their scales averaged 7 inches, for this agrees with the 7 to 8 inches estimated as the average size at 1 year attained by southern New England cod, based on collections of juveniles. In Table 44, which follows, therefore, the extremes in the calculated sizes for each age group are due partly to a difference in age, as measured by months. This is particularly evident in the I-year class, which may include individuals as young as about 8 months and as old as about 15 months, but would not be so evident with the higher age classes, for the first year's discrepancy, not being cumulative, would tend to be of less and less importance in comparison with the actual differences in the rates of growth which do exist.

TABLE 44.—*Frequency distribution of the calculated lengths at the end of each year of life, as determined from the scales of cod caught on Nantucket Shoals during the summer of 1923*

Length in inches	Complete years of growth									
	1	2	3	4	5	6	7	8	9	10
3	5									
4	34									
5	104									
6	131									
7	147									
8	74	1								
9	40	2								
10	30	8								
11	7	30								
12	1	39								
13		70								
14		76	1							
15		94	4							
16		85	18							
17		80	28	1						
18		49	48	1						
19		23	57	1						
20		10	82	5						
21		5	94	17	1					
22		1	110	29						
23			51	58						
24			38	80	2					
25			20	103	11	1				
26			4	72	17					
27			2	49	26					
28				21	22	3				
29				9	11	3	1			
30				4	13	7				
31					8	3	1			
32					2	8	1			
33						8	3			
34						3	2	1		
35							2	1		
36							3	1		
37								2		
38								1	2	
39									1	
40									1	
41										1
Total	573	573	557	450	113	36	13	6	4	1
Average length	6.7	15.1	20.8	24.8	27.7	31.1	33.6	36.1	38.7	41.0

These calculated sizes for each year of life may be subject to a small correction because body and scale growth are not in exact proportion. But that they are approximately correct is indicated by their close agreement with the ages with respect to a known size, of the samples of fish listed in the table and graph which follow:

TABLE 45.—*Age of cod as determined from the scales*

Length in inches	Summer-caught cod, by age and size																	
	South Channel, June, 1929					Nantucket Shoals, May to September, 1923						Nantucket Shoals, July, 1924						
	3½	4½	5½	6½	7½	2½	3½	4½	5½	6½	7½	1½	2½	3½	4½	5½	6½	7½
12																		
14																		
15																		
16												1						
17																		
18													1					
19	2																	
20						2							1	1				
21	2					1	3							17				
22			1				5	1					2	32				
23	2						8	2						70	1			
24		2					10	8						69	7			
25		3					14	17						56	21			
26		1					9	37						21	22			
27		2	1				6	41	5	1				8	26	2		
28		1	4					40	7	1					26	12		
29			3					30	9	4					18	16	1	
30			4					16	9	3					15	24	4	
31			2					10	4	2					13	29	4	1
32				1	1			1	5	1					1	22	1	
33				1					2	2						9	7	1
34				1	1				2	4						10	6	
35										1	2					2	2	
36										7	2						1	2
37																	2	3
38											2						1	
40																	1	1
41																		1
Total	6	9	15	3	2	3	55	203	43	26	6	1	4	274	150	126	30	9
Av. length	21.0	25.6	28.6	33.0	33.0	20.3	24.4	27.4	29.8	32.5	36.3	16.0	20.5	23.8	27.4	30.8	33.3	36.4

TABLE 45.—*Age of cod as determined from the scales*—Continued

Length in inches	Summer-caught cod, by age and size												Autumn-caught cod, by age and size				
	Nantucket Shoals, July, 1928					Summary							Nantucket Shoals, October, 1923				
	1½	2½	3½	4½	5½	1½	2½	3½	4½	5½	6½	7½	2¾	3¾	4¾	5¾	6¾
12	1					1											
14																	
15																	
16						1											
17		1					1										
18							1										
19			1					3									
20			2	1			3	3	1				4	1			
21				1			1	22	1				2				
22			2				2	39	1	1			6	1			
23			2					82	3					3			
24			1					80	17					5	1		
25				1				70	42					11	5		
26				1				30	61					11	21	1	
27			1	2				15	71	8	1			14	31		
28									67	23	1			3	28	3	
29									48	28	5				27	5	
30									31	37	7				13	3	
31					1				23	36	6	1			5	2	
32									2	27	3	1			1	2	
33										11	10	1				2	
34										12	11	1				2	
35										2	3	2				1	1
36											8	4					1
37											2	3					
38											1	2					
40											1	1					
41												1					
Total	1	1	9	6	1	2	8	344	368	185	59	17	12	49	132	21	2
Average length	12.0	17.0	22.2	24.3	31.0	14.0	20.0	23.8	27.4	30.4	32.9	36.0	21.2	25.6	27.9	30.5	34.5

Length in inches	Autumn-caught cod, by age and size																			Winter-caught cod, by age and size, Atlantic City, N. J., March, 1928			
	Nantucket Shoals, October, 1928						Cholera bank, November, 1927			Cholera Bank, November, 1928				Summary									
	1¾	2¾	3¾	4¾	5¾	6¾	2¾	3¾	4¾	1¾	2¾	3¾	4¾	1¾	2¾	3¾	4¾	5¾	6¾	3	4	5	6
12	1													1									
14	1													1									
15	3													3									
16	1									1				2									
17	1													1									
18		1													1								
19		2	1				1				1				4	1							
20		6					1				4	1			15	2				1			
21		1	1				1	5				1			4	7							
22		2	1					7			1	3			9	12					2		
23			3				2	8				6			2	20				2	2	1	
24			2	1				6				1	1			14	3				11		
25			1	3				3	2			3	1			18	11				14	1	
26				4				4				2	1			17	26	1			3		
27				3								1	2			15	36				6	1	
28				3									1			3	32	3				1	
29													1				28	5			1	3	
30													1				14	3				1	
31													1				6	2					1
32					1												1	3					
33						1												2	1				
34																		2					
35																		1	1				
36																			1				
37																							
38																							
40																							
41																							
Total	7	12	9	14	1	1	5	33	2	1	6	18	9	8	35	109	157	22	3	3	39	8	1
Average length	14.9	20.1	22.6	26.3	32.0	33.0	21.2	23.2	25.0	16.0	20.1	23.5	27.4	15.0	20.6	24.3	27.7	30.5	34.6	22.0	24.9	27.5	31.0

The calculated lengths (broken line) in Figure 33 include a large part of the fish given in Table 44, while the lengths at time of capture include all those given in Table 45. The calculated lengths suggest that during their earlier growth the fish had been slightly smaller at each year of age than the fish of those same ages proved to be when measured. But the difference is so small that the curves confirm rather than contradict each other with respect to the approximate sizes attained at particular ages.

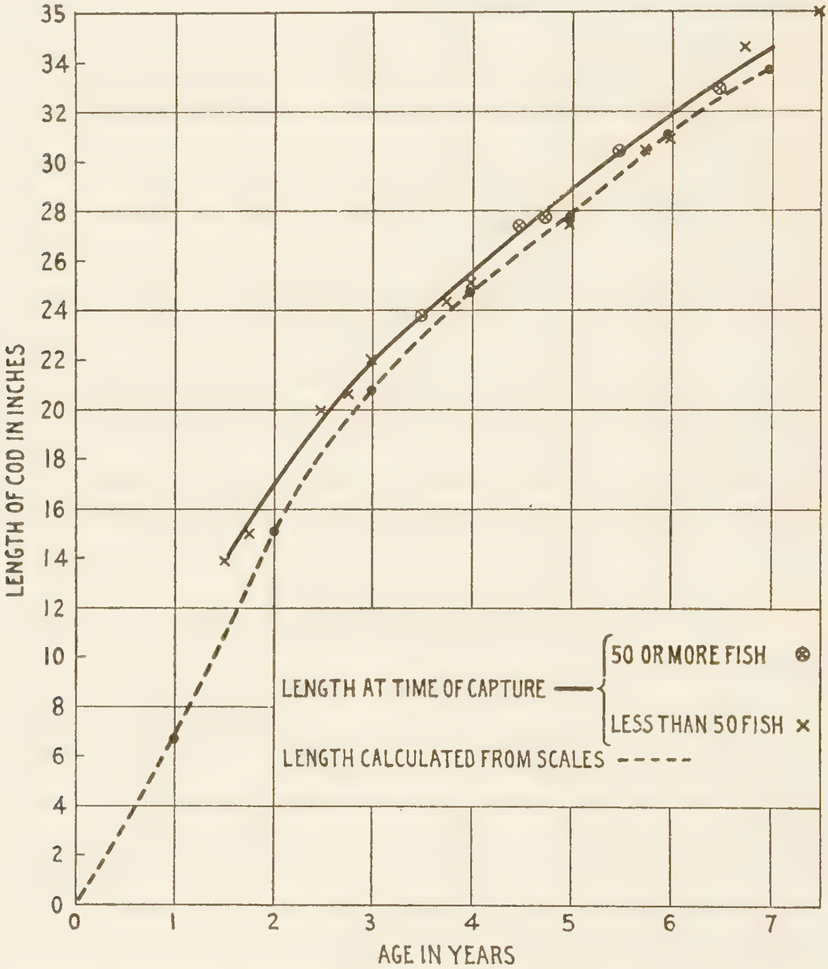

FIGURE 33.—Rate of growth of cod caught to the southward of Cape Cod, as determined from their scales

It is interesting to see whether the dominant lengths of the cod living on Nantucket Shoals during this experiment were in agreement with the growth curve. An attempt to do this is made in Table 46. In this case the age was first estimated according to the lengths of the fish and the season when they were caught, without regard to their scales.

Table 46.—*Estimated ages of Nantucket Shoals cod, based on season of capture and lengths of the fish* [1]

Estimated age in years	Average length of dominant size group		
	B group	*C* group	*D* group
1¾			15.1
2¼		19.0	
2½		20.2	
2¾		21.3	18.3
3¼			20.4
3½	23.9		21.0
3¾	24.6	24.4	21.5
4¼	25.6		
4½			24.0

[1] These data were obtained from Table 37.

All these fish were caught in the same immediate locality (between Round Shoal and Rose and Crown buoys), and while the *B* and *C* cod were dominant during the years 1924 to 1926, the *D* fish were dominant during the years 1926 to 1928. This is perhaps the first time that observations dealing with the growth of the cod have been made over a period of years on the same stock of fish living in a particular locality, and to do this it was necessary, of course, that a good part of the population remain localized from one year to the next.

That these estimated ages are approximately correct is shown by the agreement of the *B* and *C* groups with the growth curve, and this would seem to lend considerable weight to the correctness of the calculations. The *D* cod, however, suggest a rate of growth that is much different than that of the *B* or the *C* groups, for in effect the former required a year longer to reach a certain length than did either of the latter. Because of this, an examination of some of the scales was made in order definitely to locate the fish in their correct age classes. The results are given in Table 47.

Table 47.—*Age, according to scales, of certain groups of cod listed in Table 46*

Group	Average length, inches	Age [1]				Total number examined
		I	II	III	IV	
B	24.6			16		16
B	25.6			2	11	13
C	21.3		50			50
C	24.4		1	21		22
D	15.1	49	3			52
D	18.3		48	2		50
D	20.4			25		25
D	24.0			10	45	55

[1] The age given here represents completed years of growth. For example, the III-year old fish had 3 annuli on their scales and were in their fourth year.

The segregation of ages given in Table 47 seems to prove conclusively that the distribution given in Table 46 is essentially correct, hence it appears that the *D* cod grew more slowly than the fish belonging to either of the other groups.

The cause of this difference in the rate of growth of the *D* cod, as compared with the other two groups, is not definitely known. It was thought that perhaps they would exhibit some peculiarities of scale growth that would set them apart from the other groups, but an examination showed that the circulus count was in general agreement with all the other samples of southern New England cod whose scales have thus far been studied, for those *D* cod listed in Table 47 had an average of about 21 in the first growth zone.

It would be natural to look to the scales of the 15.1-inch *D* cod as a means of ascertaining the early growth of this group of fish. (Table 46.) But this may have given an erroneous result, because these fish centering around 15 inches were probably the largest individuals of their class on account of the selectiveness of hook-and-line gear. However, lengths calculated from the scales of older fish showed that at the completion of the first growth zone the *C* cod were 8.1 inches long, while the *D* cod were but 6.3 inches, and that therefore much of the 3-inch difference in size between the *C* and the *D* cod at 2¾ years of age had already been made early in the life of the fish.

It was considered that the *D* cod possibly were genetically or inherently a slow-growing group. Such might be the case if they originated from eggs spawned in northern waters where cod presumably grow more slowly than they do to the southward. It is possible that under unusual circumstances the larvæ and fry from such eggs might reach the Nantucket region, but that this happened in the present instance is not likely. It is more probable that the difference in growth was due to unusually favorable conditions which may have obtained during 1923 when the *C* cod hatched as compared with 1924 when the *D* brood originated.

These various growth and age determinations might be summed up as follows:

1. Length frequencies obtained from time to time from what were presumably the same stocks of fish indicate that on Nantucket Shoals cod 15 to 26 inches long increase in length about 2½ to 4 inches a year.

2. Recaptures of tagged Nantucket Shoals cod have shown that fish 17 to 24 inches long grow about 4 inches a year, while fish 25 to 35 inches long grow about 2½ inches a year, the smaller fish in each of their length groups and those in the preceding paragraph showing a somewhat greater increment than the larger.

3. Growth was somewhat faster during the summer than from fall to spring.

TABLE 48.—*Age with respect to size*

	I	II	III	IV	V
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
Estimated from length-frequency distributions	7–8	14–16	19–22	23–25	
Calculated size, according to scale growth	7	15	21	25	27–2
Size, according to age determinations from scales		16–17	22	25–26	28–2

RÉSUMÉ OF CONCLUSIONS

1. Cod are to be found on Nantucket Shoals throughout the year, but are most abundant there from spring to fall.

2. The stock of cod living on Nantucket Shoals, consisting chiefly of young adult and nearly adult fish, is for the most part distinct from that living to the north and east of southern Massachusetts, for there is no general intermingling of the fish belonging to these regions. This conclusion is supported by the recapture records of tagged fish and by scale studies. According to the first named, only a very small percentage of the Nantucket cod stray to the north and east annually, and, conversely, only a few cod tagged to the north and east stray to Nantucket Shoals.

3. A large part of the Nantucket Shoals cod population make a fall migration into the Rhode Island-North Carolina region, where most of them remain until the spring. These fish are joined by others from the north and east of Cape Cod; but

that southern New England cod form the bulk of the fish which occupy these wintering grounds is indicated by the paucity of recaptures there of fish tagged to the northward and eastward of Cape Cod and by the general similarity in length frequencies between the population in this wintering region and the summer cod on Nantucket Shoals. In the spring the fish return eastward, the majority of them stopping to summer on Nantucket Shoals, but others, chiefly the larger fish, most of which probably came from the north and east of Cape Cod, continue on to deeper water.

4. The number of cod which take part in this migration must be large, for the catch made each winter between Rhode Island and Delaware has ranged between three and five million pounds.

5. Many of the cod spawn on these wintering grounds, but whether most of the resultant larvæ are carried southward by the currents and are lost or whether many return to New England waters and thus help replenish the stock there is not known at this time.

6. The earliest migrants go west from Nantucket Shoals about the middle of October the movement of fish reaching its height during November and subsiding toward the end of December, after which it virtually ceases. The migration back to the eastward occurs chiefly during March and April, although a few fish may return as early as December and a few as late as May.

7. Temperature, either directly or indirectly, may be the cause of this migration, for the cod leave in the fall when the water begins to cool and return eastward in the spring when it begins to warm, although there seems to be no correlation between a particular temperature and the coming or going of the fish.

8. During the summer a cod is rarely caught west of Rhode Island and relatively few even off the latter coast, although the summer bottom temperature in the New York-Delaware region is as low or lower over certain of the grounds frequented by the cod in winter than it is on Nantucket Shoals.

9. Part of the cod living on Nantucket Shoals emigrate eastward to the Chatham-South Channel region during certain summers. This emigration was most apparent during the three years from 1923 to 1925, when most of the Nantucket cod averaged upward of 25 inches in length, and was scarcely noticeable, by means of tagged fish, during the three years from 1926 to 1928, when the fish were smaller. Not only the size of the fish but temperature, too, appears to influence this emigration, for it was largest during that year (1925), which was somewhat warmer on Nantucket Shoals than any of the others.

10. Fewer cod took part in the summer eastward emigrations than in the fall westward migrations, for length-frequency distributions, recaptures of tagged fish, and the abundance of the fish as shown by the catch per unit of effort, showed that a large part of the cod population on the shoals remained localized throughout the summer.

11. The average summer cod population on Nantucket Shoals from 1923 to 1928 might be roughly estimated as between three million and four and one-half million adult and nearly adult fish.

12. The number of grown cod which live on Nantucket Shoals appears to be fairly uniform from year to year. Losses are caused by (*a*) deaths from natural causes, (b) fish taken by the fishery not only on Nantucket Shoals but also on the wintering grounds to the westward, and (*c*) emigrations to other regions. The gains are brought

about by (*a*) cod fry which take to the bottom on Nantucket Shoals and reach maturity there and (*b*) the immigration of older fish.

13. A large part of the cod fry which seek bottom on Nantucket Shoals appear to come from eggs spawned along the coast of Maine. But so few fish between 1 and 2 years of age have been found on the shoals that it is probable that the fry succeed only in a small way in keeping up the stock of adult fish.

14. The stock of cod on Nantucket Shoals is kept up chiefly by young adult and nearly adult fish which immigrate from other regions. (Recaptures of tagged fish indicate that most of these immigrants come from the offshore grounds and that very few come from alongshore to the eastward of Cape Ann.)

15. Georges Bank and South Channel, because of their proximity and the large stock of cod which they support, and because they formed the route of a good proportion of the tagged cod which immigrated to southern New England, are the most likely source of the cod which appear in schools on Nantucket Shoals from time to time.

16. The same individual cod may remain on Nantucket Shoals for two or three years or, if some of them winter to the westward, they may be found on the shoals for several successive summers. But cod do not remain on the shoals indefinitely, for the great majority of the grown fish are between 18 and 30 inches long, and the larger ones of this size group tend to move away into deeper water. Few remain after they reach 34 inches, while those above 40 inches form less than 1 per cent of the population, although in deep water on the offshore banks these latter fish may often form from 10 to 20 per cent of the catch.

17. Cod living off southern Massachusetts are approximately 7 to 8 inches long at 1 year of age, 14 to 17 inches at 2 years, 19 to 22 inches at 3 years, 23 to 26 inches at 4 years, and 27 to 29 inches at 5 years.

TABULATION OF THE RECAPTURES

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured [1]	
Tag No.	Length	Locality	Date	Date	Locality
	Inches	*Nantucket Shoals*			
11004	30	Rose and Crown buoy	Apr. 19, 1923	July 30, 1923	South Channel.
11020	34	do	do	do	Nantucket Shoals.
11037	38	do	do	June 7, 1923	Portland, Me.
11058	31	do	do	May 30, 1924	Nantucket Shoals (35½).
11161	38½	do	Apr. 27, 1923	July 16, 1923	South Channel.
11177	38¼	do	do	Oct. 15, 1927	Do.
11397	30	do	May 23, 1923	Aug. 17, 1923	Nantucket Shoals.
11446	21½	do	do	Aug. 31, 1923	South Channel.
11462	28	do	do	Oct. 24, 1923	Nantucket Shoals.
11466	32	do	do	Oct. 16, 1923	Nantucket Shoals (33½).*
11507	26¼	do	do	Dec. 29, 1923	Cape May, N. J.
11611	20½	do	May 24, 1923	Dec. 27, 1923	Manasquan, N. J.
11621	25	do	do	Jan. 7, 1925	Westhampton, N. Y. (27½).
11622	26½	do	do	Nov. 4, 1923	Seabright, N. J.
11675	26½	do	do	June 29, 1923	Off Chatham.
11714	19¼	do	May 25, 1923	July 13, 1924	Nantucket Shoals (24¾).*
11725	23	do	do	Nov. 29, 1923	Plymouth, Mass.
11726	34½	do	do	Nov. 24, 1923	Cholera Bank, N. Y. (37).
11737	30¼	do	do	May 24, 1924	Nantucket Shoals.
11746	26	do	do	July 25, 1923	Off Chatham.
11810	25¾	do	do	June 19, 1923	Do.
11833	28	do	do	July 5, 1923	Nantucket Shoals.
11863	27½	do	May 26, 1923	Dec. 11, 1923	Bayhead, N. J.

[1] In cases where a fish was measured upon recapture, the length, in inches, is given in parentheses.

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
	Inches				
11914	26½	Rose and Crown buoy	May 26, 1923	Aug. 30, 1923	Off Chatham.
11922	38	do	do	Aug. 17, 1923	Jeffreys Ledge, off Cape Ann.
11928	26¼	do	do	Oct. 24, 1923	Nantucket Shoals.
11937	26½	do	do	Oct. 15, 1923	Nantucket Shoals (26½).*
11940	31	do	do	Aug. 28, 1923	Off Chatham.
13207	30¾	do	Sept. 5, 1923	Aug. 14, 1924	South Channel.
13256	28	do	do	Dec. 4, 1923	Ship Bottom, N. J. (29).
13736	29	do	Sept. 7, 1923	Mar. 23, 1924	Jones Inlet, N. Y.
13742	25¼	do	do	Fall, 1925	Block Island Sound, R. I.
13744	32½	do	do	Sept. 11, 1924	Nantucket Shoals (34½).*
13930	25½	do	do	Fall, 1925	Block Island Sound, R. I.
14111	28	do	Oct. 3, 1923	do	Do.
14117	26¾	do	do	Apr. 11, 1924	Jones Inlet, N. Y.
14177	25¾	do	do	Nov. 16, 1923	Do.
16189	26¼	do	Oct. 14, 1923	Mar. 4, 1924	Wainscott, N. Y. (27½).
16208	30½	do	do	Aug. 4, 1925	South Channel.
16244	28	do	do	Feb. 14, 1924	Rockaway, N. Y.
16709	25¾	do	Oct. 16, 1923	Nov. 18, 1923	Cholera Bank, N. Y.
16760	26¼	do	do	May 7, 1924	Block Island, R. I.
16852	25¾	do	do	Nov. 29, 1924	Do.
16989	21¼	do	do	July 15, 1925	Nantucket Shoals.
17003	28¾	do	do	Nov. 29, 1923	Cholera Bank, N. Y.
17015	29½	do	do	Dec. 17, 1924	Cholera Bank, N. Y. (32¾).
17078	29½	do	do	Aug. 26, 1925	Off Chatham.
17422	26¾	do	Oct. 17, 1923	Oct. 28, 1923	Nantucket Shoals.
17473	27½	do	do	June 16, 1924	Off Chatham.
17484	30½	do	do	—— —, 1923	No data.
17537	25¾	do	do	July 2, 1924	Off Chatham.
17585	24½	do	do	Sept. 12, 1924	Nantucket Shoals (27¼).*
11944	26¼	Round Shoal buoy	May 26, 1923	Feb. 9, 1925	Cape Henlopen, Del. (31¼).
11945	47	do	do	June 29, 1923	Off Chatham.
11984	27½	do	do	Aug. 16, 1923	Off Gloucester, Mass.
10008	30¾	do	May 27, 1923	Oct. 24, 1923	Nantucket Shoals.
10073	27½	do	June 22, 1923	Oct. 15, 1923	Nantucket Shoals (27½).*
10094	22	do	do	Aug. 27, 1923	Nantucket Shoals.
10121	32	do	do	July 27, 1923	No data.
10224	29¾	do	do	Dec. 3, 1923	Rockaway, N. Y.
10233	32	do	June 23, 1923	Aug. 19, 1923	Off Chatham.
10239	28	do	do	do	Nantucket Shoals (28½).*
10264	30	do	do	Oct. 28, 1923	Nantucket Shoals.
10265	27½	do	do	Oct. 24, 1923	Do.
10325	22¾	do	do	July 13, 1924	Nantucket Shoals (23½).*
10336	31	do	do	Aug. 18, 1923	Nantucket Shoals (31½).*
10377	24¾	do	do	June 26, 1923	Nantucket Shoals (24¾).*
10379	27¼	do	do	July 1, 1923	Nantucket Shoals.
10409	26½	do	do	Aug. 20, 1924	Off Chatham.
10428	25	do	do	Nov. 5, 1923	Gull Island, N. Y.
10495	26¾	do	June 24, 1923	July 15, 1923	Nantucket Shoals.
10513	29	do	do	July 24, 1923	Do.
10548	29	do	do	May 8, 1924	Block Island, R. I. (30).
10552	26¾	do	do	Jan. 21, 1924	Cape May, N. J.
10588	27	do	do	Dec. 21, 1924	Atlantic City, N. J.
10645	29	do	do	Oct. 3, 1923	Nantucket Shoals (29¼).*
10651	26½	do	do	Feb. 1, 1924	No data.
10668	25	do	do	Oct. 15, 1924	Off Chatham.
10680	35	do	do	Sept. 17, 1923	Nantucket Shoals.
10706	25	do	do	Nov. 23, 1923	Rockaway, N. Y.
10708	38	do	do	Oct. 6, 1923	Nantucket Shoals (38).*
10719	31¼	do	do	Oct. 15, 1923	Nantucket Shoals (31½).*
10760	30	do	do	Nov. 13, 1923	South Channel.
10768	25¼	do	do	Oct. 6, 1923	Nantucket Shoals (25¾).*
10772	22	do	June 25, 1923	July 5, 1924	Nantucket Shoals.
10773	37	do	do	July 30, 1923	Do.
10831	29¾	do	do	Dec. 4, 1923	Ship Bottom, N. J. (31).
10861	23	do	do	Oct. 24, 1923	Nantucket Shoals.
10880	28¼	do	do	Apr. 10, 1924	No Mans Land, Mass.
10894	26¾	do	do	Dec. 3, 1923	Fire Island, N. Y.
10956	32½	do	do	Aug. 27, 1923	Off Chatham.
10980	30½	do	do	Sept. 3, 1923	Nantucket Shoals.
10997	28	do	do	Nov. 9, 1923	Narragansett, R. I.
34	27¼	do	June 26, 1923	Sept. 12, 1924	Nantucket Shoals.*
66	31¼	do	do	Oct. 24, 1923	Nantucket Shoals.
77	30	do	do	Oct. 6, 1923	Nantucket Shoals (30¼).*
86	--------	do	do	Oct. 16, 1924	Nantucket Shoals (34¼).*
172	31½	do	June 28, 1923	Jan. 18, 1924	Cape May, N. J. (31½).
184	30	do	do	Aug. 9, 1925	Off Chatham.
208	27¾	do	do	Oct. 27, 1923	Bayhead, N. J.
224	26	do	do	Oct. 4, 1923	No data.
229	30¾	do	do	Aug. 17, 1923	Nantucket Shoals.*
231	27½	do	do	Oct. 3, 1923	Nantucket Shoals (28).*

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continned			
	Inches				
231	27½	Round Shoal buoy	June 28, 1923	Oct. 15, 1923	Nantucket Shoals (98).*
232	28¾	do	do	Oct. 24, 1923	Nantucket Shoals.
248	39	do	do	Oct. 15, 1923	Nantucket Shoals (39).*
257	28¾	do	do	Fall, 1926	Block Island Sound, R. I.
272	29½	do	do	Oct. 24, 1923	Nantucket Shoals.
277	29	do	do	Oct. 4, 1923	Do.*
277	29	do	do	Jan. 5, 1924	Rockaway, N. Y.
283	31¾	do	do	Oct. 15, 1923	Nantucket Shoals (32).*
303	29½	do	do	Oct. 4, 1923	Nantucket Shoals (29¾).*
309	31¼	do	do	Oct. 3, 1923	Nantucket Shoals (32¼).*
320	24½	do	do	Nov. 2, 1923	Long Beach, N. Y.
336	26	do	do	Oct. 3, 1923	Nantucket Shoals (26¼).*
337	28½	do	do	Oct. 18, 1923	No data.
375	29½	do	do	Oct. 15, 1923	Nantucket Shoals (30).*
383	29½	do	do	—— —, 1924	No data.
12017	27¾	do	Aug. 16, 1923	Oct. 6, 1923	Nantucket Shoals (28).*
12017	27¾	do	do	Jan. 2, 1924	Rockaway, N. Y.
12058	28¾	do	do	Sept. 17, 1923	East of Orleans, Cape Cod.
12249	26	do	do	June 14, 1924	Off Chatham.
12259	26¼	do	do	Sept. 17, 1923	Nantucket Shoals.
12272	31½	do	do	May 27, 1924	Hampton Beach, N. H.
12296	26	do	do	Dec. 27, 1923	Atlantic City, N. J. (27).
408	32	do	Aug. 17, 1923	Aug. 20, 1924	Off Chatham.
420	27¼	do	do	Dec. 14, 1923	Galilee, N. J. (28).
431	27	do	do	Dec. 11, 1923	Rockaway, N. Y.
440	25¼	do	do	Sept. 26, 1924	South Channel.
453	29¾	do	do	Nov. —, 1923	Block Island, R. I.
471	30½	do	do	Aug. 9, 1825	Off Chatham.
479	28¾	do	do	Mar. 20, 1924	Off Barnegat, N. J.
513	39	do	do	Nov. 15, 1923	Cholera Bank, N. Y.
558	27½	do	do	Sept. 3, 1923	Nantucket Shoals.
572	28½	do	do	Oct. 8, 1923	Do.
627	26½	do	do	Sept. 3, 1923	Do.
632	32	do	do	Aug. 28, 1923	Do.
642	29	do	do	July 15, 1924	Nantucket Shoals (31).*
669	27½	do	do	Dec. 4, 1923	Ship Bottom, N. J. (28¼).
672	36½	do	do	Sept. 17, 1923	Nantucket Shoals.
692	33	do	do	Oct. 17, 1923	Nantucket Shoals (33).*
724	30½	do	do	Fall, 1926	Block Island Sound, R. I.
12335	19¼	do	do	June 16, 1924	Nantucket Shoals.
12345	27½	do	do	Oct. 24, 1923	Do.
12362	26½	do	do	Fall, 1925	Block Island Sound, R. I.
12415	28	do	do	May 24, 1924	Block Island, R. I. (30).
12425	29¾	do	do	Aug. 20, 1924	Off Chatham.
12457	25¾	do	do	Jan. 21, 1925	Fire Island, N. Y.
12461	26¾	do	do	Mar. 25, 1924	Point Judith, R. I.
12482	29	do	do	Dec. 6, 1923	Narragansett, R. I.
12512	30½	do	do	Aug. 27, 1924	Off Chatham.
12630	28	do	do	Mar. 9, 1925	Atlantic City, N. J. (33).
12637	23½	do	do	Nov. 29, 1923	Rockaway, N. Y.
12651	29¼	do	do	Nov. 20, 1923	Atlantic City, N. J. (30).
12690	27	do	do	Sept. 26, 1923	Nantucket Shoals.
12691	25¼	do	do	Mar. 23, 1925	Barnegat, N. J.
12714	26	do	do	Jan. 13, 1924	Cape May, N. J. (27½).
786	27	do	Aug. 18, 1923	Nov. 7, 1924	Fire Island, N. Y.
856	25½	do	do	Jan. —, 1927	Block Island Sound, R. I.
916	26¼	do	do	Sept. 17, 1923	Nantucket Shoals.
917	29¼	do	do	do	Do.
919	27	do	do	do	Do.
986	29½	do	do	Aug. 20, 1924	Off Chatham.
1122	27¾	do	do	Aug. 17, 1925	South Channel.
1163	34½	do	do	Apr. 10, 1925	Nantucket Shoals.
1172	29¾	do	do	Oct. 13, 1923	Off Chatham.
1229	28	do	do	Oct. 4, 1923	Nantucket Shoals (28½).*
1240	24¼	do	do	Oct. 9, 1923	Nantucket Shoals.
1268	25¼	do	do	Aug. 11, 1925	Off Chatham.
1439	27¾	do	do	Nov. 1, 1923	Block Island, R. I.
1471	31	do	do	Sept. 17, 1923	Nantucket Shoals.
1492	29	do	do	Mar. 24, 1924	Off Chatham.
1561	27½	do	Aug. 19, 1923	Dec. 1, 1923	Rockaway, N. Y.
1623	27	do	do	Oct. 28, 1924	Manasquan, N. J. (28).
1662	31	do	do	Aug. 26, 1925	Off Chatham.
1712	31	do	do	Apr. 14, 1924	Water Mill, N. Y. (32½).
1770	30	do	do	Nov. 26, 1923	Seabright, N. J.
1835	----	do	do	Nov. 3, 1923	Nantucket Shoals.
1866	33	do	Aug. 23, 1923	Oct. 3, 1923	Do.*
1881	28½	do	do	Aug. 20, 1924	Off Chatham.
1954	27	do	do	Apr. —, 1924	No Mans Land.
1958	23	do	do	Dec. 21, 1923	Nantucket Shoals.
1968	25¾	do	do	Sept. —, 1923	South Channel.

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
12808	28	Round Shoal Buoy	Sept. 5, 1923	Dec. 4, 1923	Ship Bottom, N. J. (28¾).
12819	28	do	do	Nov. 20, 1923	Atlantic City, N. J.
12831	29½	do	do	Nov. 2, 1923	Nantucket Shoals.
12840	29¼	do	do	July 14, 1924	Nantucket Shoals (31¼).*
12847	37	do	do	Sept. 8, 1924	Off Chatham.
13263	-------	do	do	Dec. 4, 1923	Block Island, R. I.
2028	28	do	Sept. 9, 1923	Nov. 16, 1923	Do.
2037	-------	do	do	Oct. 4, 1923	Nantucket Shoals (28½).*
2044	28½	do	do	Sept. 17, 1923	Nantucket Shoals.
2070	24¼	do	do	Oct. 6, 1923	Nantucket Shoals (25).*
2080	28½	do	do	Dec. 16, 1923	Block Island, R. I.
2094	27	do	do	Oct. 17, 1923	Nantucket Shoals (27).*
2124	30	do	do	Sept. 17, 1923	Nantucket Shoals.
2129	26	do	do	Oct. 3, 1923	Nantucket Shoals (26).*
2197	25¾	do	Sept. 10, 1923	Oct. 15, 1923	Nantucket Shoals (25¾).*
2200	30½	do	do	Oct. 4, 1923	Nantucket Shoals (30¾).*
2221	28½	do	do	June 10, 1924	South Channel.
2241	29	do	do	Aug. 9, 1925	Off Chatham.
2249	24¾	do	Sept. 11, 1923	Dec. 18, 1923	Montauk, N. Y.
2300	30	do	do	Aug. 9, 1925	Off Chatham.
2370	28½	do	do	Fall, 1926	Block Island Sound, R. I
14021	26¾	do	Oct. 3, 1923	Oct. 16, 1924	Nantucket Shoals.
14025	23¾	do	do	Jan. 5, 1924	Quonochontaug, R. I.
14084	28	do	do	Nov. 20, 1923	Coggeshall Ledge, R. I.
14287	26	do	do	Aug. 10, 1925	Nantucket Shoals.
14303	28¾	do	do	Nov. 29, 1923	Cholera Bank, N. Y.
14310	29½	do	do	Nov. 9, 1923	Rockaway, N. Y.
14349	28¾	do	do	Nov. 12, 1923	Do.
14358	27½	do	do	Nov. 22, 1923	Bradley Beach, N. J.
14383	27¾	do	do	Oct. 17, 1923	Nantucket Shoals (29).*
14451	29	do	do	Dec. 4, 1923	Beach Haven, N. J.
14489	27¼	do	do	Apr. 20, 1924	Nantucket Shoals.
14515	30¼	do	do	Mar. 24, 1925	Block Island, R. I.
14525	27½	do	do	Dec. 18, 1923	Rockaway, N. J.
14681	20½	do	do	Sept. 20, 1924	Nantucket Shoals.
14735	24	do	do	Dec. 23, 1924	Cape May, N. J. (29).
14769	25½	do	Oct. 4, 1923	July 14, 1924	Nantucket Shoals (27¼).*
14888	30¼	do	do	July 1, 1924	Nantucket Shoals.
14958	26½	do	do	Oct. 24, 1923	Do.
14975	29½	do	do	Oct. 15, 1923	Nantucket Shoals (29¾).*
15024	27½	do	do	Apr. 18, 1925	Fire Island, N. Y.
15065	20¼	do	do	Sept. 11, 1924	Nantucket Shoals (24).*
15077	28¾	do	do	Dec. 28, 1923	Rockaway, N.Y.
15085	31¼	do	do	Oct. 23, 1924	Nantucket Shoals.
15125	29	do	do	Dec. 22, 1923	Avalon, N. J.
15374	26	do	Oct. 5, 1923	Dec. 15, 1923	Atlantic City, N. J.
15466	-------	do	do	Jan. 12, 1924	Rockaway, N. Y.
15607	28	do	Oct. 6, 1923	Nov. 17, 1923	Block Island, R. I.
15616	30	do	do	Mar. 2, 1924	Rockaway, N. Y.
15645	29½	do	do	Aug. 20, 1924	Off Chatham.
15653	25¾	do	do	Oct. 10, 1923	Nantucket Shoals.
15668	29	do	do	Mar. 6, 1924	Cape May, N. J. (31).
15671	28¾	do	do	Jan. 5, 1924	Atlantic City, N. J.
15697	29¼	do	do	Apr. 13, 1924	Atlantic City, N. J. (31½).
15703	25½	do	do	June 5, 1924	Lat. 40° 50′ N., long. 70° 20′ W.
15708	29½	do	do	Apr. —, 1924	No Man's Land.
16019	27¼	do	Oct. 14, 1923	July 14, 1924	Nantucket Shoals (29½).*
16259	38	do	Oct. 15, 1923	Dec. 18, 1923	Townsends Inlet, N. J.
16282	34¾	do	do	Apr. 15, 1924	Lat. 41° 57′ N., long. 66° 46′ W.
16308	30½	do	do	Oct. 18, 1924	Nantucket Shoals (33¼).*
16486	20¾	do	do	July 16, 1924	Nantucket Shoals (24).*
16491	22	do	do	July 13, 1924	Nantucket Shoals (23¼).*
16494	28¾	do	do	July 31, 1925	Nantucket Shoals.
16565	30	do	do	May 6, 1924	Montauk, N. Y.
16592	33½	do	do	Nov. 19, 1924	Barnegat, N. J.
17281	28½	do	Oct. 17, 1923	Dec. 21, 1923	Cholera Bank, N. Y.
15798	28¾	Great Rip buoy	Oct. 8, 1923	Oct. 16, 1924	Nantucket Shoals (30¾).*
2421	27	do	do	Aug. 25, 1925	Off Chatham.
2426	26½	do	do	Dec. 18, 1923	Quogue, N. Y.
2516	28	do	do	Nov. 20, 1923	Cape May, N. J.
2540	26¾	do	do	Nov. 11, 1923	Rockaway, N. Y.
2560	31	do	do	July 22, 1924	Nantucket Shoals.
2618	31	do	do	Nov. 29, 1923	Cholera Bank, N. Y.
11212	24½	Bass Rip	May 3, 1923	Apr. 15, 1925	La Have Bank.
11215	28½	do	do	Aug. 24, 1923	Nantucket Shoals.
11256	24	do	do	Aug. 18, 1923	Off Chatham.
11312	25½	do	do	Oct. 15, 1924	South Channel.
11317	23	do	do	Nov. 24, 1923	Cholera Bank, N. Y.
11365	27	do	May 23, 1923	Aug. 5, 1923	Nantucket Shoals.
11372	28	do	do	Mar. —, 1926	Atlantic City, N. J.

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
	Inches				
12875	27½	Davis Bank	Sept. 5, 1923	Oct. 10, 1923	Nantucket Shoals.
12954	30½	do	do	Mar. 19, 1924	No data.
13064	25	do	do	Oct. 20, 1923	South Channel.
13344	29¼	do	Sept. 6, 1923	Nov. 1, 1923	Rockaway, N. Y.
13393	32¼	do	do	Aug. 29, 1925	Off Chatham.
13404	28¾	do	do	July 15, 1925	Nantucket Shoals.
13451	25½	do	do	Feb. 1, 1925	Point Judith, R. I.
13453	27¼	do	do	do	Manasquan, N. J. (27½).
13456	26¾	do	do	Aug. 5, 1925	Nantucket Shoals.
13478	27¼	do	do	Jan. 4, 1924	Anglesea, N. J.
13499	23½	do	do	Dec. 8, 1923	Coney Island, N. Y.
13584	27½	do	do	June 27, 1925	South Channel.
13586	27	do	do	Aug. 9, 1925	Off Chatham.
13640	28	do	do	May —, 1924	Block Island, R. I.
13720	21¼	do	Sept. 7, 1923	Feb. 3, 1924	Rockaway, N. Y.
13791	29¾	do	Sept. 8, 1923	Feb. —, 1925	Atlantic City, N. J.
17702	22½	Round Shoal buoy	July 13, 1924	Sept. 12, 1924	Nantucket Shoals (23).*
17720	20¾	do	do	Sept. 6, 1924	Nantucket Shoals (20¾).*
17737	27	do	do	Dec. 9, 1924	Cholera Bank, N. Y.
17745	24¼	do	do	Oct. 21, 1924	Newport, R. I.
17828	27	do	do	Aug. 20, 1924	Off Chatham.
17842	25	do	do	Sept. 11, 1924	Nantucket Shoals (25½).*
17852	28¼	do	do	do	Nantucket Shoals (28¼).*
17853	24½	do	do	Oct. 29, 1924	Beach Haven, N. J.
17866	23¾	do	do	Dec. 31, 1924	Amagansett, N. Y.
18043	26¼	do	July 14, 1924	Dec. 7, 1924	Rockaway, N. Y.
18674	?	do	July 15, 1924	Oct. 27, 1924	Nantucket Shoals (21¼).*
18674	?	do	do	Dec. 7, 1924	Cholera Bank, N. Y.
18708	23½	do	July 16, 1924	Sept. 12, 1924	Nantucket Shoals (24).*
18726	25¼	do	do	Nov. 15, 1924	Fishers Island, N. Y.
18741	22¾	do	do	Sept. 5, 1925	South Channel.
18769	22	do	do	Dec. 17, 1924	Cholera Bank, N. Y.
19122	22¾	do	July 17, 1924	Nov. 28, 1924	Jones Inlet, N. Y.
20991	26½	do	Sept. 6, 1924	June 22, 1925	Off Chatham.
21047	32½	do	do	Oct. 18, 1924	Nantucket Shoals (32¾).*
21070	24½	do	Sept. 7, 1924	Oct. 6, 1924	Nantucket Shoals.
21080	24½	do	do	Nov. 15, 1924	Rockaway, N. Y.
21216	22¾	do	Sept. 8, 1924	May 6, 1925	Nantucket Shoals (24¾).*
21216	22¾	do	do	Aug. 7, 1925	Nantucket Shoals.
21265	25¼	do	do	Oct. 16, 1924	Nantucket Shoals (25½).*
21279	22¾	do	do	May 6, 1925	Nantucket Shoals (25).*
21281	27¼	do	do	Oct. 7, 1924	Nantucket Shoals (27¾).*
21318	22	do	do	Nov. 29, 1925	Off Chatham.
21331	21¾	do	do	Oct. 27, 1924	Fire Island, N. Y.
26259	32	do	Oct. 16, 1924	Sept. 9, 1925	Off Chatham.
26360	32¼	do	do	Mar. 16, 1925	Barnegat, N. J.
26377	31¾	do	do	Aug. 17, 1925	South Channel.
26647	25	do	Oct. 18, 1924	Nov. 22, 1925	Narragansett Bay, R. I. (28).
26696	29	do	do	Sept. 9, 1925	Off Chatham.
26778	25¼	do	do	Nov. 29, 1924	Cholera Bank, N. Y.
26785	19¾	do	do	Oct. 3, 1925	Nantucket Shoals (24).*
26851	19½	do	do	Aug. 20, 1925	Nantucket Shoals.
26903	25¼	do	Oct. 22, 1924	Mar. 27, 1925	Off Race Point, Cape Cod.
21362	24¾	Between Round Shoal and Rose and Crown buoys.	Sept. 11, 1924	Aug. 28, 1926	Nantucket Shoals.
21369	26	do	do	Aug. —, 1925	No data.
21380	20½	do	do	Oct. 18, 1924	Nantucket Shoals (20¾).*
21380	20½	do	do	Sept. 12, 1925	Nantucket Shoals.
21423	26¼	do	do	Oct. 16, 1924	Nantucket Shoals (28).*
21434	25	do	do	Oct. 27, 1924	Nantucket Shoals (25¼).*
21460	33½	do	do	Mar. 15, 1926	Off Indian River Inlet, Del. (37½).
21488	27¾	do	do	Mar. 26, 1925	Atlantic City, N. J. (31½).
21523	26½	do	do	Dec. 11, 1924	Cholera Bank, N. Y.
21539	24¼	do	do	Oct. 16, 1924	Nantucket Shoals (24½).*
21557	21½	do	do	Aug. 5, 1925	Nantucket Shoals.
21586	32¼	do	do	Aug. 4, 1925	Off Chatham.
21686	22½	do	Sept. 12, 1924	Oct. 27, 1924	Nantucket Shoals (23¼).*
21695	23½	do	do	Fall, 1927	Block Island Sound, R. I.
21722	30¾	do	do	Mar. —, 1926	Atlantic City, N. J.
21728	21	do	do	Nov. 29, 1924	Rockaway, N. Y.
21780	25¼	do	do	July 8, 1926	South Channel.
21785	26	do	do	Oct. 16, 1924	Nantucket Shoals (26¼).*
21806	22¼	do	do	Aug. 6, 1925	Nantucket Shoals.
21817	26	do	do	Dec. 19, 1924	Barnegat, N. J. (27).
21824	22¾	do	do	Oct. 1, 1925	Nantucket Shoals (25½).*
21833	24¾	do	do	Aug. 4, 1925	South Channel.
21858	25½	do	do	Dec. 1, 1924	Cholera Bank, N. Y.
21908	25½	do	do	Aug. 9, 1925	Off Chatham.
21912	26	do	do	Aug. 1, 1925	Nantucket Shoals.
21928	23½	do	do	Oct. 17, 1927	Nantucket Shoals (26½).*

Table 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
	Inches				
22043	23¾	Between Round Shoal and Rose and Crown bouys.	Sept. 12, 1924	Nov. 10, 1924	Jones Inlet, N. Y. (24).
22064	23¼	do	do	Oct. 18, 1924	Nantucket Shoals (23½).*
26405	25¾	do	Oct. 16, 1924	Dec. 3, 1924	Cholera Bank, N. Y.
26445	28¾	do	do	Aug. 25, 1925	Off Chatham.
26490	24½	do	do	Aug. 27, 1925	Do.
26505	25¼	do	do	Apr. 25, 1925	Montauk, N. Y.
26600	25¾	do	Oct. 17, 1924	Oct. 24, 1925	Nantucket Shoals (30½).*
26624	22	do	do	Jan. 10, 1925	Nantucket Shoals.
26634	33¾	do	do	June —, 1925	Off Chatham.
27034	28¼	do	Oct. 25, 1924	May 15, 1925	Nantucket Shoals.
27053	34¾	do	do	Apr. 18, 1925	Fire Island, N. Y.
27379	23½	do	Oct. 27, 1924	Jan. 6, 1925	Point Judith, R. I.
27441	30¼	do	do	Mar. 17, 1925	Atlantic City, N. J.
27474	29½	do	do	Dec. 23, 1924	Amagansett, N. Y. (30).
27581	32¼	do	do	Nov. 29, 1924	Cholera Bank, N. Y.
27583	28¼	do	do	Oct. 3, 1925	Wainscott, N. Y.
27977	26¼	do	Oct. 28, 1924	Jan. 27, 1926	Montauk, N. Y.
27616	27¼	Rose and Crown buoy	Oct. 27, 1924	Aug. 9, 1925	Off Chatham.
27654	28	do	do	Aug. 5, 1925	Nantucket Shoals.
27662	33½	do	do	June 21, 1926	Georges Bank.
27686	25¾	do	do	Dec. 12, 1924	Belmar, N. J. (26).
18853	23½	5 to 8 miles ESE. of Round Shoal buoy	July 16, 1924	July 6, 1925	South Channel.
18940	27½	do	do	Aug. 20, 1924	Nantucket Shoals.
18969	35¼	do	do	Sept. 1, 1925	Do.
18974	29¾	do	do	Aug. 20, 1924	Off Chatham.
19011	28	do	do	Mar. —, 1926	Atlantic City, N. J.
19018	27¾	do	do	Nov. 10, 1924	Montauk, N. Y. (29).
19047	34½	do	do	Nov. 12, 1924	S. W. Georges Bank.
21235	27¼	do	Sept. 8, 1924	Dec. 7, 1924	Cholera Bank, N. Y.
18052	26¼	12 miles ESE. of Round Shoal buoy	July 14, 1924	Oct. 20, 1924	Nantucket Shoals.
18081	27½	do	do	Aug. 29, 1925	Off Chatham.
18112	30¾	do	do	Fall, 1924	Nantucket Shoals.
18187	24¾	do	do	—— —, 1926	No data.
18198	26¼	do	do	Oct. 26, 1925	South Channel.
18218	26	do	do	Nov. 23, 1924	Atlantic Highlands, N. J,
18264	30¾	do	July 15, 1924	Aug. 20, 1924	Nantucket Shoals.
18284	23¼	do	do	May 18, 1925	Barnstable Bay, Mass.
18329	28½	do	do	Nov. 13, 1924	Long Beach, N. Y.
18436	30¾	do	do	July 16, 1924	Nantucket Shoals.*
18474	31	do	do	Mar.—, 1926	Atlantic City, N. J.
18537	28½	do	do	Sept. 9, 1924	Nantucket Shoals.
27266	21¾	Davis Bank	Oct. 26, 1924	Aug. 27, 1925	Do.
27318	25½	do	do	Mar. 16, 1925	Barnegat, N. J.
2990	29	Round Shoal buoy	May 5, 1925	June 25, 1926	South Channel.
28015	19¾	do	do	Aug. 20, 1925	Nantucket Shoals (21¾).*
28015	19¾	do	do	Oct. 27, 1925	Great Point, Nantucket (22).
28066	25	do	do	July 26, 1926	Nantucket Shoals.
28193	36½	do	May 6, 1925	June 5, 1926	Do.
28197	25	do	do	Mar. 19, 1926	Block Island, R. I. (28).
28198	25½	do	do	Sept. 14, 1925	South Channel.
28244	25¾	do	do	Nov. 21, 1925	Bradley Beach, N. J.
28288	25¼	do	do	Nov. 23, 1925	Jones Inlet, N. Y.
28294	25¾	do	do	Aug. 18, 1925	South Channel.
28296	19¼	do	do	Oct. 3, 1925	Nantucket Shoals (20¼).*
28344	39¼	do	do	Aug. 14, 1925	Off Race Point, Cape Cod.
28349	18½	do	do	May 26, 1927	Ipswich Bay, Mass.
28253	23	do	do	Oct. 2, 1925	Nantucket Shoals (25).*
28362	25¾	do	do	Oct. 19, 1925	Block Island, R. I. (26).
28447	18¾	do	do	Aug. 17, 1925	Nantucket Shoals.
28799	19	do	do	Oct. 2, 1925	Nantucket Shoals (20½).*
28890	28	do	do	Oct. 3, 1925	Nantucket Shoals (28).*
28892	27	do	do	Aug. 20, 1925	Nantucket Shoals (27½).*
28968	25	do	May 7, 1925	Aug. 21, 1925	Nantucket Shoals (26¼).*
28971	31	do	do	Sept. 15, 1925	Monhegan Island, Me.
28987	26¼	do	do	Nov. 30, 1925	Fire Island, N. Y.
29024	27	do	do	Aug. 20, 1925	Nantucket Shoals (27¼).*
29054	29	do	do	Aug. 27, 1925	Off Chatham.
29065	25½	do	do	Jan. —, 1926	Little Duck Island, Mount Desert, Me.
29091	23¼	do	do	Oct. 9, 1925	South Channel.
29092	34½	do	do	Dec. 19, 1925	Georges Bank.
29112	17¾	do	do	Aug. 20, 1925	Nantucket Shoals (19¾).*
29459	18	do	May 8, 1925	Dec. 15, 1925	Atlantic City, N. J. (20).
29559	27½	do	do	Aug. 11, 1925	Off Chatham.
31388	32	do	June 7, 1925	Aug. 25, 1925	Do.
31391	29	do	do	Oct. 26, 1926	Off Freeport, N. Y.
31409	23¾	do	do	Sept. 9, 1925	Off Chatham.
31627	24¼	do	June 10, 1925	Oct. 3, 1925	Nantucket Shoals (24¼).*
31683	24	do	do	Apr. 4, 1926	Portland, Me.
31756	18½	do	do	Aug. 20, 1925	Nantucket Shoals (19¼).*

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
	Inches				
31857	18	Round Shoal buoy	June 11, 1925	Oct. 31, 1926	Coggeshall Point, R. I. (20).
31892	24¾	do	do	Oct. 12, 1925	Nantucket Shoals.
31905	25¼	do	do	— —, 1925	No data.
36886	23	do	Aug. 20, 1925	Jan. 11, 1926	Cape May, N. J. (25).
36898	22½	do	do	Oct. 3, 1925	Nantucket Shoals (23).*
36901	25½	do	do	Oct. 5, 1926	Nantucket Shoals.
36909	25	do	do	Dec. 7, 1925	Off Chatham.
36933	16½	do	do	Sept. 1, 1927	Nantucket Shoals (27¾).*
36964	21¾	do	do	Oct. 25, 1925	Monomoy Point, Cape Cod.
37041	20¾	do	Aug. 21, 1925	Aug. 28, 1926	Nantucket Shoals.
37238	21½	do	do	Oct. 3, 1925	Nantucket Shoals (22¼).*
37965	20¼	do	Aug. 25, 1925	Dec. 29, 1925	Rockaway, N. Y. (21).
39855	28	do	Oct. 1, 1925	Nov. 28, 1926	Cholera Bank, N. Y. (31).
39870	25¾	do	do	Sept. 8, 1926	Nantucket Shoals (27).*
39878	26	do	do	July 20, 1926	Stellwagen Bank.
39885	26	do	do	Feb. 16, 1926	Boston Bay.
39899	28¾	do	do	Aug. 16, 1926	Off Chatham.
39922	21¼	do	do	Nov. 19, 1925	Galilee, N. J. (21¾).
39946	29½	do	do	Nov. 17, 1927	Rockaway, N. Y.
39968	37¼	do	do	Fall, 1927	Mount Desert, Me.
40087	20½	do	Oct. 2, 1925	Dec. 11, 1925	Atlantic City, N. J.
40102	19¾	do	do	Mar. 22, 1926	Cape Henlopen, Del. (21).
40107	26½	do	do	June —, 1926	Nantucket Shoals.
40117	22	do	do	June 5, 1926	Do.
40127	31	do	do	Mar. 19, 1926	30 miles SE. from Atlantic City (31½)
40135	21	do	do	July 22, 1927	Off Chatham.
40152	27¼	do	do	Apr. 9, 1927	Barnegat, N. J.
40444	28	do	Oct. 3, 1925	Nov. 22, 1925	Rockaway, N. Y.
40459	27½	do	do	July 16, 1926	South Channel.
40473	19½	do	do	Aug. —, 1926	Do.
40516	19¾	do	do	June 23, 1927	Nantucket Shoals (24½).*
40529	28½	do	do	Nov. 10, 1925	Rockaway, N. Y.
40453	18¾	do	do	Sept. 8, 1926	Nantucket Shoals (19½).*
40556	20¾	do	do	July 26, 1926	Nantucket Shoals.
40558	16¾	do	do	Sept. 21, 1926	Do.
40581	22	do	do	May 11, 1926	Off Chatham.
40681	19¾	do	Oct. 6, 1925	Oct. 5, 1926	Nantucket Shoals.
40710	20½	do	do	July 26, 1926	Do.
40742	21½	do	do	Mar. 7, 1926	Montauk, N. Y.
40763	29¼	do	do	Nov. 23, 1925	Fire Island, N. Y.
40767	22	do	do	Sept. 25, 1926	South Channel (27).
42263	23¾	do	Oct. 24, 1925	Oct. 5, 1926	Nantucket Shoals.
42278	20	do	do	Oct. 4, 1926	15 miles off Cape Cod Light.
42295	19½	do	do	Jan. 3, 1927	Amagansett, N. Y.
42322	22¼	do	do	June 5, 1926	Nantucket Shoals.
28599	28½	Rose and Crown buoy	May 6, 1925	Nov. 10, 1925	Fisher's Island, N. Y.
28703	31	do	do	Dec. 11, 1925	Amagansett, N. Y.
29194	28	do	May 7, 1925	Sept. 15, 1925	Nantucket Shoals.
40223	21½	do	Oct. 2, 1925	Jan. 25, 1926	Watermill, N. Y. (23).
40246	28	do	do	Nov. 21, 1925	Bradley Beach, N. J.
40254	27¼	do	do	Oct. 6, 1925	Nantucket Shoals.*
40255	30½	do	do	Mar. 30, 1926	Barnegat, N. J.
40283	21	do	do	Nov. 29, 1925	Rockaway, N. Y. (22).
40336	22¾	do	do	Dec. 8, 1925	Jones Inlet, N. Y.
40338	22¼	do	do	Dec. 15, 1925	Amagansett, N. Y.
40340	28½	do	do	Feb. 8, 1926	Montauk, N. Y.
40356	29	do	do	— —, 1926	No data.
40359	22½	do	do	Feb. 8, 1926	Atlantic City, N. J. (25)
40895	22¼	do	Oct. 6, 1925	Nov. 10, 1925	Jones Inlet, N. Y.
40928	21¾	do	do	— —, 1926	No data.
40937	20¼	do	do	Feb. 9, 1926	Atlantic City, N. J.
40960	20¼	do	do	Oct. 15, 1927	South Channel.
40972	21½	do	do	Nov. 4, 1926	Rockaway, N. Y. (25).
42123	16¾	do	Oct. 24, 1925	June 23, 1927	Nantucket Shoals (23).*
42126	21¼	do	do	Sept. 11, 1926	Nantucket Shoals (24½)
31915	34¾	6 to 12 miles ESE. of Round Shoal buoy	June 11, 1925	Aug. 7, 1925	Nantucket Shoals.
31923	24¼	do	do	Oct. 2, 1925	Do.
31956	30	do	do	July 31, 1925	Do.
31983	29	do	do	May 12, 1926	South Channel.
32040	23	do	do	Oct. 18, 1925	Do.
32065	27¼	do	do	Aug. 26, 1925	Off Chatham.
32072	23¼	do	do	Aug. 25, 1925	Do.
32083	27¼	do	do	June 17, 1927	Off Chatham (31¼).*
32108	28	do	do	July 26, 1925	Off Salem, Mass.
32136	33¼	do	do	Aug. 17, 1925	South Channel.
32184	27	do	do	Sept. 12, 1925	Nantucket Shoals.
32198	24¼	do	do	Sept. 7, 1926	Do.
32214	19¼	do	June 12, 1925	— —, 1925	No data.
32216	27½	do	do	Dec. 14, 1925	Atlantic City, N. J. (28¾).
32327	27½	do	do	July 6, 1926	No data.

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tag No.	Length	Tagged		Recaptured	
		Locality	Date	Date	Locality
	Inches	*Nantucket Shoals*—Continued			
32341	30	6 to 12 miles ESE. of Round Shoal buoy	June 12, 1925	Apr. 10, 1926	No Mans Land, Mass. (31½).
32401	30¾	do	do	Oct. 4, 1926	Nantucket Shoals.
32410	34	do	do	July 14, 1925	South Channel.
32471	27¾	do	do	Aug. 26, 1925	Do.
32473	30¾	do	do	Aug. 29, 1925	Off Chatham.
32477	44½	do	do	Sept. 12, 1925	Nantucket Shoals.
32533	28¼	do	do	Aug. 25, 1925	Off Chatham.
32565	21¾	do	do	Sept. 9, 1925	Nantucket Shoals (25).
32576	26½	do	do	Dec. 20, 1925	Rockaway, N. Y. (26¾).
32622	23¼	do	do	Nov. 4, 1926	Nantucket Shoals.
32638	26½	do	do	May 16, 1926	Marblehead, Mass. (28¾).
32639	37	do	do	June 18, 1926	Nantucket Shoals.
32667	38½	do	do	June 27, 1925	South Channel.
32689	25½	do	do	Sept. 9, 1925	Off Chatham.
37267	18¼	Great Rip buoy	Aug. 23, 1925	—— —, 1927	No data.
37331	29¼	do	do	Mar. 30, 1926	Barnegat, N. J.
37467	20¾	do	do	Jan. 17, 1926	Cape May, N. J.
37502	28¼	do	do	Oct. 3, 1925	Nantucket Shoals.
37506	27¾	do	do	Aug. 14, 1926	South Channel.
37511	28	do	do	Sept. 27, 1926	Nantucket Shoals.
37661	22	do	do	Sept. 24, 1926	Do.
37675	29½	do	do	Nov. 7, 1925	Narragansett, R. I.
37732	29¾	do	Aug. 24, 1925	Nov. 13, 1925	Rockaway, N. Y.
37790	19¼	do	do	July 31, 1926	South Channel.
37868	29	do	do	Oct. 3, 1925	Nantucket Shoals.
37998	26	do	Aug. 25, 1925	Nov. 1, 1925	Monomoy, Cape Cod.
38002	30¼	do	do	Feb. 9, 1926	Atlantic City, N. J.
38116	23¼	do	do	Nov. 20, 1925	Do.
38214	21¼	do	do	Mar. 10, 1926	Cape May, N. J.
38216	21	do	do	Jan. 23, 1926	Jones Inlet, N. Y.
43980	19½	Round Shoal buoy	Sept. 6, 1926	May 6, 1927	Nantucket Shoals (22¼).*
44163	19½	do	Sept. 7, 1926	Apr. 4, 1927	No Mans Land, Mass.
44167	15	do	do	Jan. 19, 1927	Cape May, N. J.
44546	28½	do	Sept. 8, 1926	May 1, 1927	Georges Bank.
44594	17¼	do	do	Dec. 15, 1926	Block Island Sound, R. I.
44600	25½	do	do	Mar. 7, 1927	Cape May, N. J.
44711	25¼	do	do	Aug. 13, 1927	Muskeget Channel, Mass.
44452	20½	Between Round Shoal and Rose and Crown buoys.	Sept. 7, 1926	Feb. 25, 1927	Fire Island, N. Y. (22).
44468	17¾	do	do	Nov. 30, 1927	Rockaway, N. Y.
44483	18½	do	do	—— —, 1927	No data.
44526	19¼	do	do	Dec. 4, 1926	Narragansett, R. I.
45240	25	do	Sept. 10, 1926	May 10, 1927	Off Sandy Hook, N. J.
45328	31	do	do	Dec. 10, 1926	Block Island Sound, R. I.
45362	16¾	do	do	Sept. 1, 1927	Nantucket Shoals (20½).*
45414	20	Between Rose and Crown and Great Rip buoys.	Sept. 11, 1926	Nov. 25, 1926	Monomoy, Cape Cod.
45426	21¼	do	do	Oct. 1, 1927	Nantucket Shoals.
45075	30	Great Rip buoy	Sept. 9, 1926	June 24, 1927	Nantucket Shoals (32¼).*
45407	25¾	do	Sept. 11, 1926	Oct. 29, 1926	Block Island, R. I. (26).
47472	21¼	Round Shoal buoy	May 4, 1927	Sept. 3, 1927	Nantucket Shoals (21¾).*
47483	19¾	do	do	Nov. 2, 1927	Atlantic City, N. J.
47497	20½	do	do	Nov. 26, 1927	Off Anglesea, N. J. (21½).
47499	22½	do	do	Sept. 3, 1927	Nantucket Shoals (23¾).*
47545	21½	do	May 6, 1927	Nov. 15, 1927	Galilee, N. J.
47588	18½	do	do	July 19, 1928	Nantucket Shoals (22).*
47715	20¼	do	do	Nov. 21, 1927	Bradley Beach, N. J. (24).
47731	22½	do	do	Mar. 4, 1928	Off Anglesea, N. J.
47738	20½	do	do	Sept. 1, 1927	Nantucket Shoals (20½).*
47759	21¾	do	do	July 14, 1928	Nantucket Shoals (22¾).*
47776	19¼	do	do	Nov. 16, 1927	Nantucket Shoals.
47778	18¼	do	do	June 17, 1927	Nantucket Shoals (18¾).*
47799	21½	do	do	July 21, 1928	Nantucket Shoals (25).*
47801	18½	do	do	Oct. 8, 1927	Nantucket Shoals.
47803	28½	do	do	do	Do.
47809	23½	do	do	do	Do.
47854	19	do	do	Nov. 16, 1927	Rockaway, N. Y.
47856	21¾	do	do	Aug. 31, 1927	Nantucket Shoals (22).*
47913	21½	do	do	Mar. 7, 1928	Atlantic City, N. J. (22¾).
47944	19¾	do	do	Nov. 19, 1927	Nantucket Shoals.
47965	27	do	do	Mar. —, 1928	Long Beach, N. Y.
47977	29¾	do	do	June 17, 1927	Nantucket Shoals (29¾).*
48020	21½	do	do	Nov. 19, 1927	Nantucket Shoals.
48022	20	do	do	Sept. 1, 1927	Nantucket Shoals (20¼).*
48025	21½	do	do	Nov. 19, 1927	Nantucket Shoals.
48053	22½	do	do	June 23, 1927	Nantucket Shoals (23).*
48075	22½	do	do	June 27, 1927	Nantucket Shoals.
48076	28	do	do	July 20, 1928	Nantucket Shoals (30).*
48087	20	do	do	June 22, 1927	Nantucket Shoals (20½).*

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
	Inches	*Nantucket Shoals*—Continued			
48090	21	Round Shoal buoy	May 6, 1927	June 18, 1927	Nantucket Shoals (21¼).*
48118	20	do	do	Mar. 7, 1928	Rockaway, N. Y.
48141	19½	do	do	July 19, 1928	Nantucket Shoals (22).*
48155	26	do	do	Aug. 31, 1927	Nantucket Shoals (26½).*
48160	31¼	do	do	July 19, 1928	Nantucket Shoals (34).*
48269	24	do	do	Sept. 1, 1927	South Channel.
48324	20¼	do	do	Nov. 19, 1927	Long Beach, N. Y.
48328	20¼	do	do	Sept. 2, 1927	Nantucket Shoals (20¾).*
48492	22¼	do	May 7, 1927	Jan. 15, 1928	Block Island Sound, R. I.
48866	19	do	June 17, 1927	Feb. —, 1929	Atlantic City, N. J.
48879	27½	do	do	Jan. 12, 1928	Amagansett, N. Y.
48887	20½	do	do	Nov. 17, 1927	Cholera Bank, N. Y.
48950	27¼	do	do	Jan. 11, 1928	Manasquan, N. J.
48956	24½	do	do	Sept. 15, 1927	Nantucket Shoals.
48984	24½	do	do	Nov. 8, 1927	Block Island, R. I.
49055	22¾	do	do	Feb. 4, 1929	Cape May, N. J. (28½).
49068	24¼	do	June 18, 1927	Jan. 4, 1928	Cape May, N. J.
49103	19¾	do	do	Sept. 2, 1927	Nantucket Shoals (20¾).*
49126	19	do	do	May 1, 1928	No Mans Land, Mass.
49127	22¾	do	do	Dec. 21, 1927	Western part of Georges Bank.
49141	21¾	do	do	Sept. 1, 1927	Nantucket Shoals (22).*
49222	21¾	do	do	Aug. 15, 1927	South Channel.
49247	20¾	do	do	Sept. 1, 1927	Nantucket Shoals (21).*
49270	20¼	do	do	Oct. 27, 1927	Seabright, N. J. (21½).
49330	21¼	do	do	—— —, 1928	No data.
49344	20¾	do	do	Dec. 3, 1928	Cape May, N. J.
49412	21¼	do	June 22, 1927	Dec. 1, 1927	Off Manahawkin, N. J.
49428	21¼	do	do	Nov. 8, 1927	Long Beach, N. Y.
49544	25½	do	June 23, 1927	Nov. 16, 1927	Rockaway, N. Y.
49562	20½	do	do	Dec. 7, 1927	Manasquan, N. J.
49579	20	do	do	Dec. 23, 1927	Westhampton, N. Y. (21).
49589	22¾	do	do	Dec. 14, 1927	Off Spring Lake, N. J. (23¾).
49616	23¾	do	do	Sept. 3, 1927	Nantucket Shoals (23¾).*
49621	21	do	do	Dec. 11, 1928	Cholera Bank, N. Y. (25).
49649	19	do	do	Nov. 10, 1927	No Mans Land, Mass.
49697	29¼	do	do	Apr. 3, 1928	Nahant, Mass.
52829	20½	do	Aug. 31, 1927	Nov. 13, 1927	Rockaway, N. Y.
52835	22½	do	do	July 30, 1928	Off Chatham.
52836	22½	do	do	Nov. 26, 1928	Rockaway, N. Y.
52853	20	do	do	Jan. —, 1929	Atlantic City, N. J. (27½).
52856	21	do	do	—— —, 1928	No data.
52863	22	do	do	Dec. 31, 1928	Seabright, N. J.
52887	22	do	do	Jan. 10, 1928	Cape May, N. J.
52955	20	do	do	Oct. 18, 1928	Georges Bank.
52973	21¼	do	do	Nov. 26, 1927	Cholera Bank, N. Y. (22).
53003	25½	do	do	Nov. 6, 1927	Atlantic City, N. J. (26).
53015	21	do	do	Nov. 14, 1928	Point Judith, R. I. (23).
53016	23½	do	do	Apr. 5, 1928	Wildwood, N. J. (26).
53029	20¾	do	do	Oct. 15, 1927	South Channel.
53098	24	do	do	Nov. 22, 1927	Stellwagen Bank.
53216	21½	do	Sept. 1, 1927	Dec. 7, 1927	Coney Island, N. Y.
53254	21¼	do	do	July 20, 1928	Nantucket Shoals (23¾).*
53289	21½	do	do	Nov. 8, 1928	Rockaway, N. Y. (24).
53305	20¼	do	do	Nov. 19, 1927	Nantucket Shoals.
53308	20¾	do	do	Nov. 14, 1927	Beach Haven, N. J.
53323	19	do	do	Nov. 18, 1927	Rockaway, N. Y.
53325	20½	do	do	Nov. 16, 1927	Do.
53336	20	do	do	Feb. 25, 1928	Manasquan, N. J.
53349	23	do	do	Mar. 5, 1928	Wildwood, N. J. (24).
53364	21¼	do	do	Apr. 4, 1929	Block Island, R. I.
53404	22¾	do	do	Nov. 23, 1927	Rockaway, N. Y. (23½).
53488	22½	do	do	Nov. 18, 1927	Rockaway, N. Y.
53583	20¾	do	do	Oct. 29, 1927	Off Seaside Park, N. J. (21).
53439	20¼	do	Sept. 2, 1927	Nov. 14, 1927	Rockaway, N. Y.
53616	22	do	do	Dec. 19, 1927	Spring Lake, N. J. (22½).
53634	23	do	do	Dec. 4, 1928	Off Willis Wharf, Va.
53707	22¼	do	do	Oct. 17, 1927	Nantucket Shoals (22¼).*
53707	22¼	do	do	Sept. 29, 1928	Nantucket Shoals.
53710	20½	do	do	Jan. 8, 1928	Seabright, N. J.
53758	25	do	do	Dec. 11, 1927	Jones Inlet, N. Y.
53785	20¾	do	do	Nov. 14, 1928	Long Branch, N. J. (25½).
53837	21¼	do	Sept. 3, 1927	Nov. 2, 1928	Rockaway, N. Y. (25).
53987	24½	do	do	Dec. 11, 1927	Rockaway, N. Y. (25¾).
53990	24¾	do	do	Nov. 16, 1927	Rockaway, N. Y.
54038	23¼	do	do	Nov. 7, 1927	Beach Haven, N. J.
54051	23¾	do	do	Nov. 10, 1927	Galilee, N. J. (24½).
54053	22	do	do	Oct. 8, 1928	Coggeshall Point, R. I.
54108	23¾	do	do	Nov. 20, 1927	Bradley Beach, N. J. (25).
54221	19½	do	do	Nov. 16, 1927	Nantucket Shoals.
54257	20¼	do	do	July 20, 1928	Nantucket Shoals (23½).*

TABLE 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
		Nantucket Shoals—Continued			
	Inches				
50391	19¾	Between Round Shoal and Rose and Crown buoys.	June 25, 1927	Nov. 23, 1927	Barnegat Inlet, N. J. (20½).
50414	21¾	do	do	Apr. 15, 1928	Block Island Sound, R. I.
55687	20¾	do	Oct. 14, 1927	Aug. 20, 1928	South Channel.
55731	21½	do	do	June 10, 1929	Nantucket Shoals (25½).*
56822	18	do	Oct. 17, 1927	Mar. —, 1928	Delaware Bay.
56895	20¾	do	do	Nov. 21, 1927	Bradley Beach, N. J.
49776	20¼	Between Rose and Crown and Great Rip buoys.	June 24, 1927	Sept. 15, 1927	Nantucket Shoals.
50074	27¼	do	do	Feb. 24, 1928	Wildwood, N. J.
50082	22½	do	do	Oct. 25, 1927	Nantucket Shoals.
50089	18¼	do	do	Sept. 29, 1928	Do.
50099	23¾	do	do	Apr. —, 1928	Cape May, N. J.
50249	30	do	June 25, 1927	Sept. 10, 1928	Nantucket Shoals.
55864	25¾	do	Oct. 15, 1927	Jan. 7, 1928	Long Beach, N. Y.
55905	23	do	do	Feb. 7, 1928	Long Branch, N. J. (23½).
55926	29	do	do	Dec. 3, 1928	Cape May, N. J.
55928	29½	do	do	Apr. 5, 1928	Wildwood, N. J.
55941	29½	do	do	Apr. 19, 1929	Atlantic City, N. J.
56022	20½	do	do	Mar. —, 1928	Off Delaware Bay (22½).
56140	23¾	do	do	—— —, 1928	No data.
56186	22½	do	do	Mar. 26, 1928	Barnegat, N. J. (23¾).
56251	25¼	do	Oct. 16, 1927	Jan. 1, 1929	Wildwood, N. J.
56296	32½	do	do	Feb. 15, 1928	No Mans Land, Mass.
56321	25¾	do	do	Feb. 4, 1928	Beach Haven, N. J.
56333	30	do	do	July 2, 1928	South Channel.
56379	35¼	do	do	Mar. 10, 1928	Chesapeake Bay, Va.
56414	24¼	do	do	Aug. 3, 1929	Nantucket Shoals.
56450	28¾	do	do	Mar. 15, 1927	Atlantic City, N. J.
56522	23¼	do	do	Sept. 14, 1928	Nantucket Shoals.
56524	23	do	do	Aug. 15, 1929	South Channel.
56656	27	do	Oct. 17, 1927	Nov. 16, 1927	Fire Island, Inlet, N. Y.
56688	24¼	do	do	do	Cholera Bank, N. Y. (25).
56691	25¼	do	do	Dec. 4, 1928	Off Hog Island, Va.
56717	22½	do	do	Apr. 3, 1928	Gay Head, Mass.
56718	34	do	do	Apr. 20, 1929	Sakonnet Point, R. I.
56732	29	do	do	Sept. 23, 1928	Georges Bank.
56741	24¾	do	do	Winter, 1927-28	Wildwood, N. J.
48339	19½	Great Rip buoy	May 7, 1927	Sept. 15, 1927	Nantucket Shoals.
49806	20½	do	June 24, 1927	Feb. 28, 1928	Wildwood, N. J.
49882	21	do	do	Sept. 10, 1928	Nantucket Shoals.
49883	24½	do	do	Mar. 4, 1928	Amagansett, N. Y.
50346	20	do	June 25, 1927	Winter, 1927-28	Wildwood, N. J. (24).
48736	22¾	Davis Shoal	June 17, 1927	Sept. 24, 1927	Nantucket Shoals.
48741	22¾	do	do	Nov. —, 1928	Block Island, R. I.
48847	21	do	do	Feb. 14, 1928	Seabright, N. J.
48851	19	do	do	—— —, 1928	No data.
58080	21½	Round Shoal buoy	July 14, 1928	Spring, 1929	Block Island, R. I.
58092	20¾	do	do	Nov. 28, 1928	Rockaway, N. Y.
58106	24	do	do	Feb. 14, 1929	Delaware Bay.
58153	23¾	do	do	Feb. 20, 1929	Rockaway, N. Y.
58368	23¾	do	July 19, 1928	Nov. 13, 1928	Do.
58369	27	do	do	Nov. 25, 1928	Barnegat, N. J.
58423	24½	do	do	Nov. 8, 1928	Rockaway, N. Y.
58512	23¾	do	do	Oct. 26, 1928	Nantucket Shoals.
58580	24	do	do	Nov. 22, 1928	Point Judith, R. I. (26).
58611	22½	do	July 20, 1928	Oct. 26, 1928	Nantucket Shoals (23).*
58621	25½	do	do	Oct. 11, 1929	Nantucket Shoals.
58709	21½	do	do	Nov. 15, 1928	South Channel.
58745	23	do	do	Nov. 19, 1928	Rockaway, N. Y. (26¼).
58808	22½	do	do	Nov. 13, 1928	No Mans Land, Mass.
58824	20	do	do	May 18, 1929	Siasconset, Nantucket.
58849	22	do	do	Nov. 19, 1928	Fire Island, N. Y.
60953	24	do	Oct. 24, 1928	Dec. 1, 1928	Rockaway, N. Y.
61060	28¾	Between Round Shoal and Rose and Crown buoys.	Oct. 26, 1928	Jan. 2, 1929	Seabright, N. J.
61066	35	do	do	Jan. —, 1929	Atlantic City, N. J.
61071	27	do	do	Dec. 13, 1928	Do.
61082	26	do	do	Nov. 14, 1928	Newport, R. I.
61122	25½	do	Oct. 28, 1928	June 14, 1929	Nantucket Shoals (26).*
58894	24½	Great Rip buoy	July 21, 1928	Dec. 3, 1928	Cape May, N. J. (26).
61247	26	do	Oct. 29, 1928	Mar. 25, 1929	"Old Ground," Cape Henlopen, Del. (26½)
		Other points			
3405	29½	Woods Hole, Mass.	Jan. 6, 1926	June 16, 1926	Chatham Bay, Mass.
3535	30	do	do	Jan. 27, 1927	Amagansett, N. Y. (32½).
3602	30½	do	do	Jan. 20, 1928	No Mans Land, Mass.

TABLE 49.—*A list of all the recaptures of cod tagged between the nantucket shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
	Inches	*Other points*—Continued			
3612	29½	Woods Hole Mass	Jan. 6, 1926	Mar. 15, 1926	Sea Girt, N. J.
3764	31½	do	do	Jan. 15, 1926	Montauk Point, N. Y.
3776	28	do	do	Apr. 12, 1928	Sandy Hook Bay, N. J.
3805	33	do	Jan. 7, 1926	Mar. 27, 1926	Montauk Point, N. Y. (33).
3845	27¾	do	do	Apr. 17, 1926	Jones Inlet, N. Y.
3862	25½	do	do	Aug. 10, 1926	Block Island, R. I.
3960	31¼	do	do	Apr. 6, 1927	Brentons Reef, R. I.
3969	27¼	do	do	Mar. 11, 1926	Nantucket Shoals.
3984	30	do	do	Dec. 13, 1926	Block Island, R. I.
4036	35	do	do	Jan. 25, 1926	Watermill, N. Y.
4041	32	do	do	Jan. 13, 1926	Amagansett, N. Y.
4051	26½	do	do	Feb. 13, 1926	Montauk, N. Y.
4091	29	do	do	July 21, 1927	Nantucket Shoals.
4098	29½	do	do	Jan. 3, 1927	Newport, R. I. (33½).
4106	27	do	do	Feb. 13, 1926	Westhampton, N. Y.
4184	26	do	do	Mar. 20, 1928	Montauk, N. Y.
4187	31½	do	do	Aug. 10, 1926	Block Island, R. I.
4213	24½	do	do	Mar. 21, 1926	Montauk, N. Y.
4220	26	do	do	Dec. 14, 1927	Cholera Bank, N. Y.
4242	32	do	do	May 2, 1926	Montauk, N. Y. (32¾).
4329	26½	do	Jan. 3, 1927	Jan. 18, 1927	Block Island, R. I.
4334	24½	do	do	May 7, 1927	Sandy Hook, N. J. (26).
4353	29	do	do	Jan. 10, 1927	Block Island Sound, R. I.
4460	22	do	do	Jan. 8, 1927	Block Island, R. I. (22).
4495	28¼	do	do	do	Watch Hill, R. I.
4546	23	do	do	Jan. 19, 1928	Point Judith, R. I.
4569	23¼	do	do	Jan. 24, 1928	Amagansett, N. Y. (31).
4577	27	do	do	Apr. 15, 1927	Off Narragansett Bay, R. I.
4605	32½	do	do	Jan. 8, 1927	Amagansett, N. Y.
4728	21¾	do	do	May 5, 1927	Watch Hill, R. I.
4756	29	do	Jan. 13, 1928	Apr. 4, 1928	Westhampton, N. Y. (30).
4774	25	do	do	Feb. 8, 1928	Atlantic City, N. J. (26).
4818	24	do	do	Apr. 15, 1928	Watch Hill, R. I.
4891	20¾	do	do	Feb. 11, 1928	Easthampton, N. Y.
4933	25	do	do	Spring, 1928	Off Rhode Island.
4952	24½	do	do	Oct. —, 1928	Nantucket Shoals.
4964	25½	do	do	Jan. 18, 1928	Block Island, R. I.
7390	21¾	do	do	Mar. 25, 1928	Nantucket Shoals (22).
7407	28	do	do	Mar. —, 1928	Cape May, N. J.
7488	28	do	do	Apr. 15, 1928	Newport, R. I.
7495	23¾	do	do	Mar. 12, 1928	Gay Head, Mass.
7509	27¼	do	do	Jan. 27, 1928	Amagansett, N. Y.
7535	23¼	do	do	July 23, 1928	South Channel.
7545	28	do	do	Mar. —, 1928	Block Island, R. I.
7596	24¾	do	do	Spring, 1928	Off Rhode Island.
7599	28½	do	do	Jan. 18, 1928	Block Island, R. I.
11072	28	No Mans Land	Apr. 21, 1923	June 1, 1923	No data.
11114	23½	do	Apr. 24, 1923	Oct. 17, 1925	No Mans Land.
11152	26½	do	Apr. 26, 1923	Aug. 24, 1923	South Channel.
42348	28	do	Oct. 28, 1925	Feb. 8, 1926	Block Island, R. I.
42396	27¼	do	do	Oct. 28, 1926	No Mans Land.
10012	35	Off Chatham	May 27, 1923	Sept. 17, 1923	Off Chatham.
47101	27	do	May 3, 1927	Mar. 27, 1929	Sandy Hook, N. J. (32½).
47108	23¼	do	do	July 12, 1927	Off Chatham.
47152	21¼	do	do	May —, 1928	Ipswich Bay, Mass.
47183	29½	do	do	July 25, 1927	South Channel.
47210	29¼	do	do	Mar. 28, 1928	Wildwood, N. J.
47215	27¼	do	do	July 10, 1928	South Channel.
47287	18¼	do	May 4, 1927	Jan. 12, 1928	Jones Inlet, N. Y. (19).
47371	23¾	do	do	May 11, 1928	Off Chatham.
47378	27¾	do	do	do	Do.
47384	19½	do	do	Jan. 23, 1928	Cape May, N. J.
48512	23¼	do	June 16, 1927	Nov. 21, 1927	Barnegat Inlet, N. J. (24).
48533	25¼	do	do	July 26, 1927	South Channel.
48610	22	do	do	Oct. 26, 1928	Nantucket Shoals.
48628	28	do	do	Jan. —, 1928	Wildwood, N. J.
49392	27½	do	June 22, 1927	July 26, 1927	South Channel.
49398	19½	do	do	Sept. 10, 1928	Nantucket Shoals.
57704	23½	Cholera Bank, N. Y	Nov. 14, 1927	Dec. 27, 1927	Jones Inlet, N. Y.
57706	20½	do	do	Nov. 17, 1927	Do.
57726	22¾	do	Nov. 15, 1927	Feb. 17, 1928	Off Long Beach, N. Y. (23½).
57735	23¼	do	Nov. 16, 1927	Nov. 21, 1927	Bradley Beach, N. J.
57762	23½	do	do	Dec. 11, 1927	3 miles north of Ambrose Lightship, N. Y.
57787	22	do	Nov. 17, 1927	May 15, 1928	Nantucket Shoals.
57829	23	do	Nov. 20, 1927	Jan. 15, 1929	Delaware Bay (27).
57857	28	do	Nov. 21, 1927	Dec. 26, 1927	Easthampton, N. Y.
61347	21¾	do	Nov. 21, 1928	Jan. 19, 1929	Cape May, N. J.

Table 49.—*A list of all the recaptures of cod tagged between the Nantucket Shoals region and southern New Jersey*—Continued

[Those marked with an asterisk (*) were taken by one of the tagging vessels, the *Halcyon* or the *Albatross II*]

Tagged				Recaptured	
Tag	Length	Localitly	Date	Date	Locality
		Other points—Continued			
	Inches				
61380	21¼	Cholera Bank, N. Y	Nov. 23, 1928	Dec. 16, 1928	Off Long Beach, N. Y.
61390	22	do	do	Nov. 29, 1928	3 miles north of Ambrose Lightship, N. Y.
57887	23	Atlantic City, N. J	Mar. 25, 1928	July 22, 1928	Nantucket Shoals.
61823	25½	Wildwood, Cape May, N. J	Dec. 31, 1928	Feb. 20, 1929	Wildwood, N. J. (25¾).
61869	22¾	do	Jan. 1, 1929	Jan. 23, 1929	Wildwood, N. J. (23¼).
61927	27¼	do	Jan. 22, 1929	Jan. 27, 1929	Delaware Bay.
61936	26	do	do	Aug. 1, 1929	South Channel.
61507	24½	do	Feb. 13, 1929	Apr. 14, 1929	Cape May, N. J.
61569	22½	do	Feb. 16, 1929	Mar. 21, 1929	Do.
62065	28	do	Mar. 18, 1929	Aug. 2, 1929	South Channel.
62125	28½	do	Mar. 27, 1929	Oct. 12, 1929	Nantucket Shoals.

Table 50.—*The following recaptures were reported too late to enter into the records*

Tagged				Recaptured	
Tag No.	Length	Locality	Date	Date	Locality
	Inches				
7553	25	Woods Hole, Mass	Jan. 13, 1928	Oct. 12, 1929	Nantucket Shoals.
62860	33¾	Lat. 41° 17′ N., long. 69° 24′ W	June 13, 1929	June 22, 1929	South Channel.
62883	26	do	do	Sept. 5, 1929	Do.
62222	18½	Nantucket Shoals, between Round Shoal and Rose and Crown bouys.	June 10, 1929	Nov. 24, 1929	Rockaway, N. Y. (18¾).
62253	21	do	do	Nov. 2, 1929	Seabright, N. J.
62247	22½	do	do	Nov. —, 1929	Delaware Bay.
62450	19½	do	June 11, 1929	Jan. 8, 1930	Delaware Bay (20).
62538	25¼	do	do	Dec. 10, 1929	Amagansett, N. Y.
62564	26½	do	do	Sept. 1, 1929	South Channel.
62581	22	do	do	Oct. 11, 1929	Nantucket Shoals.
62644	23¾	do	do	Oct. 14, 1929	Do.
62806	26¼	do	June 12, 1929	June 22, 1929	South Channel.
62982	25	do	June 14, 1929	Sept. 16, 1929	Nantucket Shoals.
48846	19½	Nantucket Shoals, Davis Shoals	June 17, 1927	Feb. 22, 1930	Cape May, N. J.
62682	32¾	Nantucket Shoals, Great Rip bouy	June 11, 1929	July 16, 1929	Do.
56456	28½	do	Oct. 16, 1927	Mar. 21, 1930	Delaware Bay (34).
61248	29½	do	Oct. 29, 1928	Nov. 23, 1929	Cape May, N. J.
61239	18	Nantucket Shoals, Rose and Crown buoy	Oct. 28, 1928	Mar. 1, 1930	Delaware Bay.
61748	31¾	Cape May, N. J	Dec. 29, 1928	Jan. 4, 1930	Off Jones Inlet, N. Y.
61540	24¾	do	Feb. 13, 1929	Oct. 31, 1929	Elberon, N. J. (26¼).
61579	20¾	do	Feb. 16, 1929	Dec. 12, 1929	Off Fire Island Inlet, N. Y.
62049	20½	do	Mar. 18, 1929	Apr. 22, 1930	Cape May, N. J.
62144	27¾	do	Apr. 7, 1929	Mar. 10, 1930	Virginia Beach, Va.
62182	24¾	do	Apr. 8, 1929	Oct. 16, 1929	Fire Island, N. Y.

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INVESTIGATIONS ON PLANKTON PRODUCTION IN FISH PONDS[1]

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INTRODUCTION

PURPOSE OF THIS INVESTIGATION

While the pond culture of fresh-water fishes is an art of many years' standing in certain European countries, notably Germany, in this country pond-fish culture is a relatively recent development. Hence, very little accurate knowledge applying to pond-fish culture in this country is at present available. With the depletion of the native fish stock in our natural waters and with the growing demand for game fish to stock inland waters, the need for more exact knowledge as to how to rear fish in ponds has become apparent. During the last few years the Bureau of Fisheries, through its division of scientific inquiry, has attempted to solve some of the problems pertaining to the rearing of game fish in ponds to the fingerling stage rather than to distribute them as fry. One of the chief problems has been that of increasing the food supply for the fish.

The amount of available fish food may be increased either directly or indirectly: Directly through artificial feeding, indirectly through increasing the natural food supply. It is the policy of the bureau in its pond-culture work with warm-water fishes to increase fish production by the indirect method of using fertilizers to increase the natural food supply rather than to resort to artificial feeding.

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[1] This report is based on a doctor's thesis submitted before the graduate faculty of the University of Wisconsin. It was submitted to the Bureau of Fisheries for publication Mar. 13, 1930.

The question may arise as to how the addition of fertilizers increases fish production. The effect is, as already indicated, indirect. In general, the first step is through the plant life of the pond. The production of animal matter anywhere depends in the last analysis on photosynthesis or, in other words, on plant growth. The plant growth in turn depends on the energy derived from the sun, the carbon dioxide of either the atmosphere or of the water, and the presence in solution of suitable forms of nitrogen, phosphorus, potassium, etc. In other words, the amount of plant growth is limited by the amount of sunshine and the availability of those elements that go into the making of plant tissue, and also by the presence of those elements which, although they do not appear as constitutents of plants, are yet necessary to bring about proper growth. Whenever one or the other of these factors—that is, sunshine, carbon dioxide, nitrogen, phosphorus, etc.—becomes exhausted, plant growth ceases. The element that becomes exhausted and thus causes a cessation of plant growth is called a limiting factor, for it is those elements that either become exhausted completely or become reduced to concentrations too low to be effective that determine the amount of growth. Through the use of proper fertilizers all the elements, except sunshine, that enter into the process of plant growth may be intensified; and, provided enough sunshine is present, an increase in plant growth may be expected. This increase in plant growth should in the end mean an increase in fish production. The second step is through the organisms that feed on the plants and which, in turn, are consumed by the game fish. Among these intermediate organisms may be mentioned certain small crustacea like copepods and cladocera, the immature stages of some aquatic insects, and herbivorous forage fish.

In the case of fish ponds, one difficulty arises; namely, that certain plants may grow that are not available for fish food except in so far as they eventually die and decay and become fertilizer. In the fish ponds we are, therefore, more particularly interested in the algæ, and the production of fish may be expected to be more closely related to the production of algæ than to the total plant growth.

In the practice of pond fertilization, the assumption has quite generally been made (see review of literature, p. 140) that phosphorus and nitrogen are the only elements that have to be supplied by the fertilizer, and that the other necessary elements are present in sufficient quantities. In a few instances the assertion has even been made that only phosphorus becomes exhausted and that this element is the limiting factor.

One object of this paper is to present data to show that the addition of various fertilizers to the pond water increases the growth of the plankton algæ (phytoplankton) and likewise increases the production of copepods, cladocera, and rotifers (zooplankton)—organisms that feed directly or indirectly on phytoplankton. Hence, there are presented in this paper the results of quantitative studies on the plankton of ponds that were fertilized and also of control ponds that were not fertilized. Along with the data on plankton counts and volumes (in the case of the net plankton) are presented data showing the amount of organic matter in the water—the organic matter in the bodies of the plankton organisms as well as the unorganized organic matter suspended in the water—that can be removed with an electric centrifuge (see section on methods). Both sets of data show that the addition of fertilizer has a beneficial effect.

Another object of this paper is to present the results of a series of chemical determinations that have been made on the pond water. The reason for making these determinations is obviously as follows: If we are going to fertilize ponds intelligently, we must first of all have some idea as to what elements necessary to photosynthesis are becoming exhausted. In other words, which are the limiting factors? In an attempt to answer this question, the following chemical determinations were made quantitatively: Organic nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, dissolved phosphorus, organic phosphorus, chloride, free carbon dioxide, phenolphthalein alkalinity, pH, and dissolved oxygen. It is important that all the four forms of nitrogen and the two forms of phosphorus be determined, because an element must not only be present but it must be in an available form. In the case of nitrogen, for instance, the nitrate alone is immediately available to a majority of algæ. Some of the blue-green appear to utilize compounds of ammonia, but the nitrate seems to be preferred by most. The organic nitrogen and the nitrite nitrogen are not immediately available to any of the algæ. Hence, to determine total nitrogen or even total inorganic nitrogen would be misleading. The same is also true of the phosphorus, for it is only the dissolved phosphorus that is immediately available for plant growth. A major object of these chemical determinations was to find out if the inorganic nitrogen or the dissolved phosphorus ever became completely exhausted. The data presented in this report show that nitrate and ammonia nitrogen were always present, even in the unfertilized ponds. The dissolved phosphorus, however, becomes at times completely exhausted.

The determinations of pH and phenolphthalein alkalinity were made for the purpose of finding out whether or not the hydrogen-ion concentration may be a controlling factor in the growth of plankton. The results seem to show that within fairly wide limits the hydrogen-ion is not the controlling factor. The high values for alkalinity and for pH seem to be the direct result of photosynthesis. In fact, it looks very much as if the rate of photosynthesis controls alkalinity rather than the reverse. Another reason for making these determinations was to see just how great these variations really are.

That pH and alkalinity in these ponds would be governed very largely by the rate of photosynthesis would probably be expected, for carbonic acid is undoubtedly the chief acid in these pond waters. Now photosynthesis uses not only the free carbonic acid but some of that in loose combination with the metals calcium and magnesium. The withdrawal of carbonic acid would tend to make the water alkaline.

The determinations of free CO_2 were made for several reasons. In the first place, we wanted to know how close the correlation is between pH and CO_2. If the hydrogen-ion concentration in these pond waters is due largely to CO_2, then the pH values and the values for CO_2 should be in an inverse ratio; that is, as the CO_2 goes up the pH should go down. This assumption is borne out by the results. Another reason for making determinations of free CO_2 was to see if this acid might ever be present in sufficiently large quantities to become detrimental to fish life. Still a third reason is that since CO_2 is one of the raw materials for photosynthesis it may become a limiting factor.

The dissolved oxygen determinations are important for two reasons. In the first place, it seemed worth while to determine just how abundant this element is and to what extent it varies in amount. Another reason was to see if the dissolved oxygen would ever become low enough to endanger fish life. This was of especial importance in those cases where organic fertilizers were added to the water. Apparently the amount of fertilizers used in our pond work did not seriously affect the oxygen supply.

The chloride determinations were made to discover any relationship between the available chloride and the amount of plankton. The results suggest that a plentiful supply of chloride was always available, and that chloride was not a limiting factor.

Along with these chemical determinations there were also made observations on temperatures and on turbidity. Turbidity, since it determines the extent to which sunlight can penetrate the lower strata of water, may have an important influence on photosynthesis.

To attempt to analyze all the data that are presented in this report at the present time would seem premature to the writer. Although the data may seem impressive in volume, it is manifestly inadequate to explain and to correlate the physical, chemical, and biological processes that are taking place in a fish pond. An explanation which may hold true for one pond may not fare so well when the data from another pond are examined. The writer has, therefore, purposely refrained from drawing many hard and fast conclusions. A few conclusions that seemed warranted by the data presented in this report, as well as by other unpublished data, are given at the end of this paper. The writer hopes, however, that while this paper fails to solve the life processes of a fish pond, it may act as a stimulus for further work along this line.

LITERATURE

Various attempts have been made to link up the productivity of the sea and of bodies of fresh water with certain definite chemical elements. The dissolved phosphorus has been designated as a limiting factor by Atkins and Harris (1924). They found that one pond which they studied contained 0.055 p. p. m. of dissolved phosphorus in spring, and another pond contained 0.04 p. p. m. During the summer no phosphorus at all or only very small amounts were found. They concluded that the further growth of algæ had been prevented by the exhaustion of the dissolved phosphorus early in spring.

Fisher (1924) reported that at the Bavarian Pond Fishery Experiment Station an increase in carp production was obtained when superphosphate or basic slag were used as fertilizers. Fertilizers rich in nitrogen and potassium but containing no phosphorus also increased carp production, but to a very much lesser degree. Fisher concluded from these experiments that the available phosphorus was the limiting factor and that nitrogen and potassium were generally present in sufficient amounts and did not have to be added through the fertilizer.

Brandt (1919) reported that the amount of soluble phosphorus in the surface water of the North Sea was smallest in May and June and largest in November and February. Atkins (1926) found that the dissolved phosphorus at various places off the coast of England reached a minimum in summer and a maximum in winter. The decrease in the soluble phosphorus in spring was proportionate to the increase in phytoplankton.

Harvey (1926) found that the nitrate nitrogen was completely exhausted in the English Channel during August of 1925. In 1927 in summarizing our present knowledge of the productivity of the ocean this author concludes "There is an excess supply of the requirements for photosynthesis with the exception of phosphate and nitrate," and "The fertility of an ocean will depend for the most part on two factors; namely, the length of time taken by the corpses of marine organisms and excreta to decay, and the length of time taken by the phosphate and nitrate so formed to come again within the range of algal growth."

Juday et al (1928), who studied 88 lakes situated in northeastern Wisconsin, state, "No definite evidence was found to indicate that soluble phosphorus is a limiting factor in the production of phytoplankton in those lakes." Again, "In some lakes which support a relatively large crop of plankton there is no decrease in the amount of soluble phosphorus, or only a very slight one, in the upper water from May to July or August." They therefore failed to confirm Atkins's theory at least in as far as the 88 lakes studied are concerned.

Data will be presented in this paper that tend to show that soluble phosphorus may be a limiting factor in fish ponds, but it will also be shown that phosphorus is not the only limiting factor. Evidence will also be presented to show that inorganic nitrogen was not a limiting factor.

Czensny (1919) calls attention to the fact that the free CO_2 may directly limit the production of algæ and indirectly the production of those organisms that feed on algæ. Birge and Juday (1927) have shown that the soft-water lakes in northeastern Wisconsin that are extremely low in fixed CO_2 do as a rule contain considerable quantities of free CO_2. In the hard-water lakes studied by Birge and Juday there is generally enough of what has been called the half-bound CO_2 to make up for any deficiency in free CO_2. The algæ can make use of the half-bound as well as of the free. The data that will be presented in this paper confirm the conclusions of Birge and Juday as far as the hard waters are concerned.

That the addition of fertilizer to the pond water has an effect on plankton production has been shown by Von Alten (1919). In Von Alten's experiments, the effect of fertilizer was specially noticeable in the case of diatoms. He observed an increase in the number of species, the number of individuals, and an increase in size. Pauly (1919) noticed that inorganic fertilizers exerted a beneficial effect upon Volvox, rotifers, Cladocera, and copepods, but the number of diatoms was decreased.

METHODS OF ANALYSIS AND EXPRESSION OF RESULTS

The different forms of nitrogen and the chlorides were determined according to the procedures outlined by the American Public Health Association in Standard Methods of Water Analysis (1926). The free CO_2, the phenolphthalein alkalinity, and the dissolved oxygen were determined as outlined by Juday (1911). The soluble phosphorus was determined by Denige's method (1921). The total phosphorus was determined by a method outlined by Juday et al. (1928). The difference between the total and the soluble phosphorus has been designated as the organic phosphorus. All phosphorous determinations were made on centrifuged water. For the determination of hydrogen-ion a La Motte colorimetric outfit was employed. Transparencies were determined by means of Secchi disk. The organic matter in the plankton was determined as described by Juday (1926). The net plankton was determined volumetrically by straining a definite volume of water through a Wisconsin plankton net. The concentrated sample obtained in this way was then transferred from the plankton bucket to a graduated tube of an electric centrifuge and was centrifuged at a moderately high speed for two minutes. The volume in cubic centimeters was then read off directly from the tube. It might be stated here that volumetric determinations of net plankton are not always a very good index of productivity.

In the first place many of the smaller organisms will not be retained by the plankton net, and in the second place some organisms pack much more closely in the centrifuge tube than others. For the centrifuge plankton counts, half a liter of water was run through the Foerst centrifuge. The algæ in the centrifuge plankton were enumerated in the usual manner.

Most of the chemical results are expressed in parts per million (p. p. m.) in the text. The organic matter of the net plankton also called the organic matter or in some cases the net loss on ignition has been expressed in milligrams per liter. In the tables the expression milligrams per liter alone has been used. The hydrogen-ion concentrations are as a matter of convenience expressed in terms of pH values rather than in terms of the actual hydrogen-ion concentration. According to this notation the maximum hydrogen-ion concentration corresponds to the minimum pH value. The transparency is expressed in inches.

The volumetric net plankton determinations are expressed in cubic centimeters per 10 liters of water. The algæ of the centrifuge plankton are expressed in numbers per liter of water.

The expressions ammonia-nitrogen, nitrate-nitrogen, and nitrite-nitrogen when used in this paper have the same meaning as they have in Standard Methods of Water Analysis. The values for phosphorus are stated in terms of the element rather than in terms of PO_4 or P_2O_5.

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C POND EXPERIMENTS

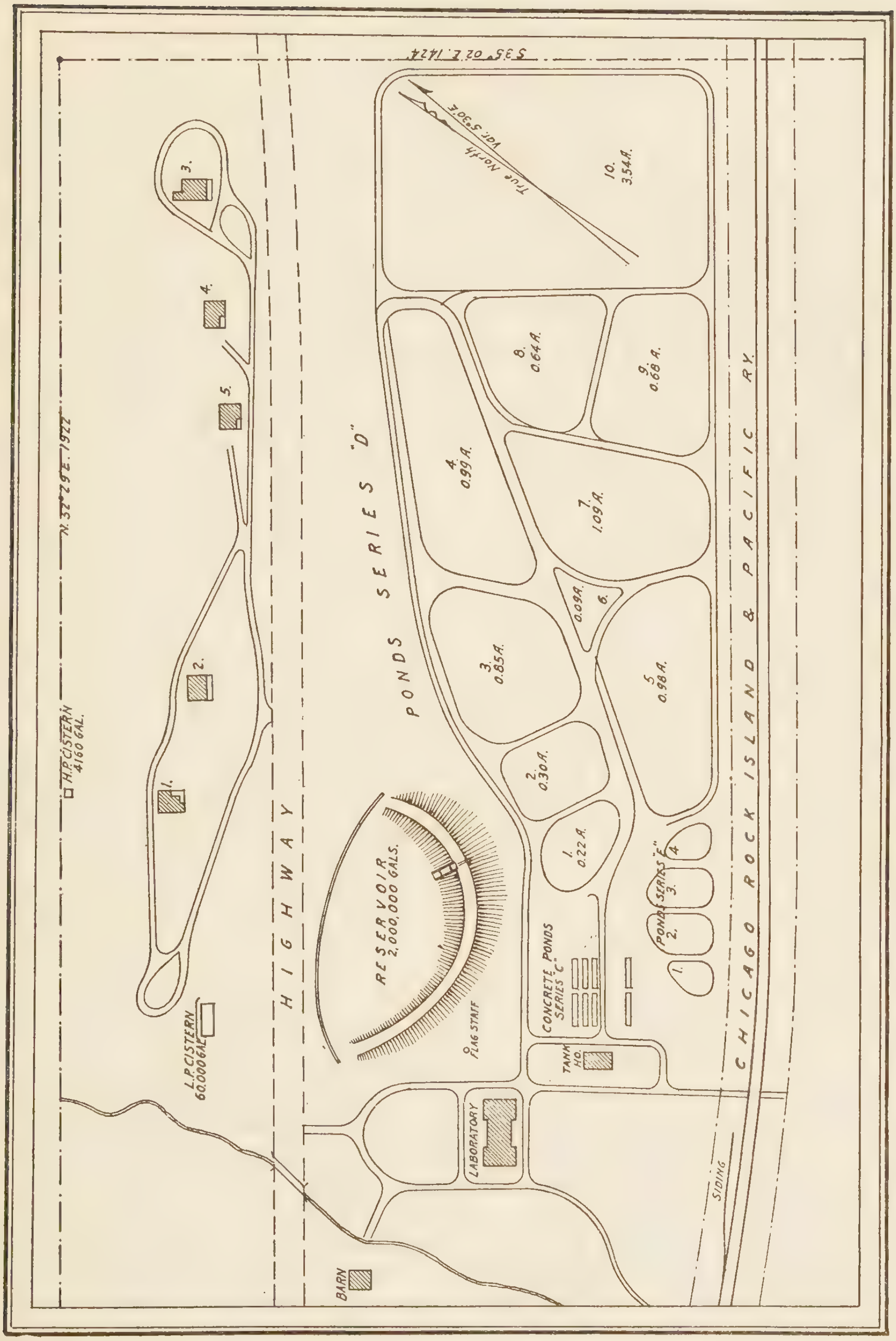
DESCRIPTION OF PONDS

The C ponds are a series of six small cement ponds, all of the same size and shape. Their arrangement with respect to one another is shown in Figure 1. These ponds are 50 feet long and 8 feet wide and each has an area of 378 square feet. The ends are in the form of a semihexagon, which accounts for the reduced area. The depth of the water in these ponds was 14 inches at the upper end and 20 inches at the lower end. This would give each pond a volume of water of approximately 530 cubic feet.

PURPOSE OF THIS EXPERIMENT

The series of experiments in the C ponds was carried on to determine the effectiveness of soybean meal, shrimp bran, and superphosphate as pond fertilizers. Accordingly C 1 was fertilized with superphosphate, C 2 with soybean meal, and C 3 with shrimp bran. C 4 was used as a control without any fertilizer. An analysis of the soybean meal gave the following results: Total phosphorus 1.2 per cent, nitrogen (exclusive of nitrate nitrogen) 24 per cent, and total organic matter 60.9 per cent. A similar analysis of shrimp bran gave the following results: Total phosphorus 1.9 per cent, nitrogen (exclusive of nitrate nitrogen) 7.1 per cent, and total organic matter 52.6 per cent. The superphosphate is the 16 per cent acid phosphate.

The amounts of fertilizer used and the dates on which it was applied are shown in Table 1.


S 35° 02' E. 1424
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H.P. CISTERN 4160 GAL.
L.P. CISTERN 60,000 GAL.
1.
2.
3.
4.
5.
HIGHWAY
PONDS SERIES "D"
True North
Var. 5° 30' E.
10. 3.54 A.
8. 0.64 A.
9. 0.68 A.
4. 0.99 A.
7. 1.09 A.
0.09 A. 6.
3. 0.85 A.
5. 0.98 A.
2. 0.30 A.
1. 0.22 A.
RESERVOIR 2,000,000 GALS.
FLAG STAFF
CONCRETE PONDS SERIES "C"
PONDS SERIES "E"
1.
2.
3.
4.
TANK HO.
LABORATORY
BARN
SIDING
CHICAGO ROCK ISLAND & PACIFIC RY.

FIGURE 1.—Partial view of the station grounds at Fairport, Iowa, showing positions of the D and E series of ponds

No fish were kept in these ponds during the course of the experiment. The effects of the fertilizers are determined by the amount of plankton and the weight of the organic matter per unit volume of water.

LIMNOLOGICAL DATA

The original plan for these experiments had been to take net plankton samples only, but it was later decided to make a complete series of limnological observations. The first plankton samples were taken on June 7. Then from June 13 to September 6 they were taken regularly several times a week—sometimes daily. From September 15 to 20 they were again taken daily. The other limnological observations made on this series of ponds cover the period from June 27 to September 19, 1928. The results discussed below are tabulated in Tables 2 to 5, and the variations are shown graphically in Figures 2 and 3.

Temperature.—Tests made at the beginning of the experiment and at intervals during the experiment showed that the maximum variation in the temperatures for this series of ponds did not exceed ½° C. at any one time. Therefore, the temperature of one pond was assumed to hold good for the series. I might repeat here that the C ponds are all of the same size and depth, have the same exposure, and are all free from any kind of rooted vegetation.

Table 3 shows that the minimum temperature of 18.3° C. occurred on June 27. The maximum of 25° C. occurred on July 7 and on August 9. Temperature does not seem to be a limiting factor in this experiment.

Transparency.—No measurements of transparency were made on these ponds. They were practically water-tight, and very little water had to be added during the season. This made it possible for the suspended silt to settle. Any differences in the transparency were due, therefore, to differences in the amount of plankton and the dust-fine detritus resulting from the decomposition of the dead plankton. In the control pond, C 4, the bottom was plainly visible throughout the season. In C 1 the bottom was visible until the plankton became very abundant. C 3 was very turbid early in the season, but as the plankton, especially the phyto-plankton, decreased, the water became more transparent, so that at the end of the season the bottom was visible. C 2 was always very turbid. This is correlated with the large amount of organic matter present throughout the season. It appears that at least as far as the C ponds are concerned productivity is not governed by transparency, but rather that the reverse is the case.

Hydrogen-ion concentration.—The results of pH determinations are shown in Table 2. In C 1 the pH value in samples taken at 8 a. m. ranged from 8.5 on June 27 to 9.0 on July 30. In samples taken later in the day the pH varied from 8.8 to 9.1. These figures show that the water in this pond was at all times distinctly alkaline in reaction to phenolphthalein. The variations in pH and temperature are shown in Figure 2. In C 2 the pH of 8 a. m. samples ranged from 7.55 on August 9 to 9.0 on July 30. In the afternoon samples it ranged from a maximum of 8.75 on September 13 to a minimum of 8.5 on September 19. The minimum of 7.55 occurred at the same time as the maxima for free CO_2 and ammonia nitrogen. One of the maxima for temperature occurs on the same date. The variations of temperature and pH are shown in Figure 2. In C 3 the pH in the morning samples varies from 7.6 on August 20 to 9.3 on July 7. In the afternoon samples it varies from 8.7 on August 9 to 9.1 on September 13 and 19. The maximum pH value occurs here after an enormous decrease in the net loss on ignition. The minimum comes after a slight decrease in the net loss on ignition while the latter is on a low level already. The minimum pH is correlated also with a decrease in dissolved oxygen and a large increase in ammonia nitrogen. With a subsequent rise in the organic matter, a decrease in ammonia nitrogen and an increase in dissolved oxygen, the pH goes up again. The variations in pH and temperature in C 3 are shown in Figure 3. In C 4 the pH ranges from 7.7 to 8.8 in the morning samples and from 8.9 to 9.05 in the afternoon samples. The minimum and the maximum occur here at the beginning and at the end of the season, respectively. Figure 3 shows the variations in these values in C 4.

On the whole it may be stated that with very few exceptions the water in these ponds was alkaline with respect to phenolphthalein. Also it may be stated that as a general rule the pH maxima correspond to the minima for free CO_2 and conversely the free CO_2 maxima correspond to the minima for pH. This would suggest that the acidity or hydrogen-ion concentration is controlled by the free CO_2.

Free CO_2.—Table 2 shows that free CO_2 was never present in C 1. In fact there existed always a CO_2 deficiency or a phenolphthalein alkalinity. This alkalinity varied from a minimum of 10.10 p. p. m. on June 27 to a maximum of 68.76 p. p. m. on July 30. From this date on the phenolphthalein alkalinity decreases, at first rapidly and then more slowly, until by September 19 it is down to 11.72 p. p. m. again. The great change in the phenolphthalein alkalinity or the free CO_2 deficiency from July 19 to August 9 is associated with a rapid rise and decline in the net loss on ignition, also by an increase in pH. The dissolved oxygen increases during this interval from 6.62 p. p. m. to 12.21 p. p. m. and decreases again to 8.74 p. p. m. An examination of Table 6 shows that the net plankton increased from 0.1 cubic centimeter per 10 liters of water on July 19 to 3.5 cubic centimeters on July 30, and to a maximum of 9.0 cubic centimeters per 10 liters of water on August 1. On August 9 it was down to 3.8 cubic centimeters again. These plankton samples were composed almost exclusively of algæ. This, of course, would mean a very rapid rate of photosynthesis and hence the great free CO_2 deficiency and the large increase in dissolved oxygen. The variations in pH and the free CO_2 deficiency or the phenolphthalein alkalinity is shown in Figure 2.

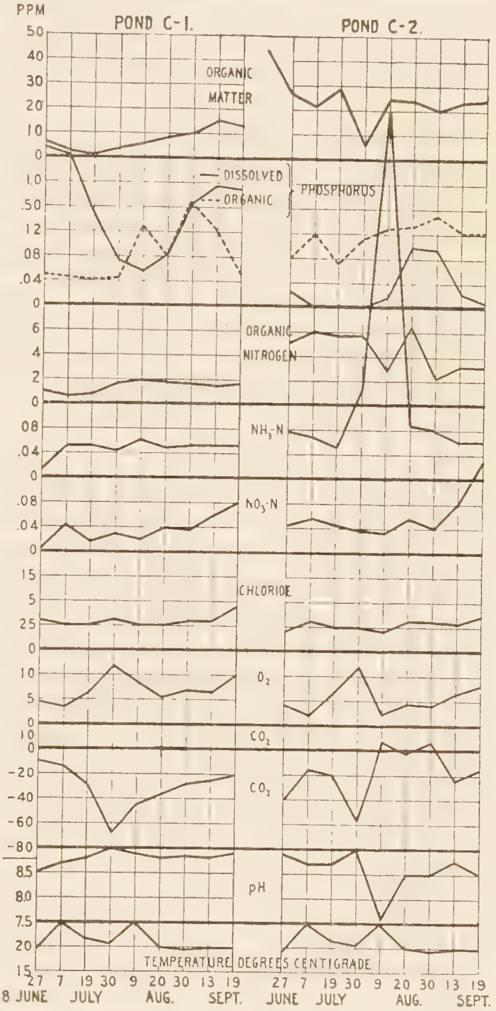

FIGURE 2.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperature in degrees C. for ponds C 1 and C 2

Table 2 shows that free CO_2 occurred only twice in pond C 2. The remainder of the time the water was alkaline to phenolphthalein, that is, a free CO_2 deficiency existed. The maximum free CO_2 deficiency amounted to 57.60 p. p. m. and the maximum free CO_2 was 7.58 p. p. m. The first occurrence of free CO_2 is associated with a rapid decrease in organic matter and the dissolved oxygen, and a very marked rise in the ammonia nitrogen. The second occurrence of free CO_2 is marked by a less-pronounced decrease in the organic matter and the dissolved oxygen, but there is a slight decrease in the ammonia nitrogen. The maximum CO_2 deficiency is accompanied by an increase in the organic matter and the volume of net plankton. The variations in free CO_2 are shown in Figure 2.

According to Table 2, free CO_2 appeared only once in C 3; namely, on August 20 when 6.06 p. p. m. were found. For the rest of the season, with one exception on July 30, when the water was neutral to phenolphthalein, there existed a free CO_2 deficiency. This CO_2 deficiency was at its height early in the season. The maximum of 85.94 p. p. m. occurred on July 7. Although this is associated with a large decrease in organic matter, the number of algæ that were present (Table 8) indicates that photosynthesis was still going on actively. However, Tables 2 and 9 show that the maximum alkalinity is not correlated with the maximum number of algæ. Later in the season the alkalinity was greatly reduced: From July 19 to August 30 it never exceeded 30.34 p. p. m. In September, however, the alkalinity increased rapidly again so that by September 19 it had reached 65.72 p. p. m. again. This rise in alkalinity in September is correlated with a rise in the number of algæ per liter of water. Figure 3 shows the variations in free CO_2.

In pond C 4 as in C 1 free CO_2 was never encountered. Table 2 shows that the phenolphthalein alkalinity here varied from a minimum of 8.08 p. p. m. on June 27 to a maximum of 45.50 p. p. m. on September 19. The minimum and the maximum phenolphthalein alkalinities correspond to the minimum and the maximum pH values. The minimum alkalinity corresponds also to the maximum for the net loss on ignition. The fact that the maximum alkalinity occurs simultaneously with the minimum for the net loss on ignition is due to the appearance of some filamentous algæ on the bottom. These algæ would not appear in the samples, yet they use up CO_2. Figure 3 shows the variations in free CO_2.

Table 2 shows that two sets of determinations of pH and free CO_2 were made on August 9. The first sample was taken at 8 a. m. and the second at 3 p. m. This was done in order to obtain some idea as to the amount of variations that may occur during a relatively short interval of time. This test was carried out on a bright day. The table shows that in C 1 the phenolphthalein alkalinity increased from 44.50 p. p. m. to 72.80 p. p. m., and the pH rose from 8.9 to 9.1. These changes are correlated with the presence of 216,000 colonies of Pleodorina and 748,800 colonies of Pandorina per liter of water. (Table 8.) These algæ used up more CO_2 for photosynthesis than they produced through respiration. Hence the increase in pH and in alkalinity. In C 2 the free CO_2 decreased from 7.58 p. p. m. to -23.34 p. p. m. and the pH rose from 7.55 to 8.7. These changes in C 2 are likewise correlated with fairly high counts for the algæ Oocystis and Chroococcus. (Table 8.) In C 3 the changes were: Phenolphthalein alkalinity from 5.06 p. p. m. to 13.14 p. p. m. and pH from 8.0 to 8.7. The changes in alkalinity are smaller in C 3 than in C 1 and C 2, but the change in pH is greater than in C 1. These changes in C 3 are correlated with fairly high counts for the algæ, Scenedesmus, Chroococcus, and Aphanizomenon.

(Table 8.) In C 4 the phenolphthalein alkalinity increased from 24.26 to 26.28 p. p. m. and the pH from 8.7 to 8.9. The changes in pH are equal to that in C 1, but are much less than in C 2 or 3. The change in alkalinity is less here than in either of the other three ponds of this series. The change in temperature between 8 a. m. and 3 p. m. was 5° C.; namely, from 25° C. to 30° C.

Dissolved oxygen.—The dissolved oxygen data are shown in Table 3. This table shows that in C 1 the dissolved oxygen varied from 4.36 p. p. m. on June 27 to a minimum of 3.43 p. p. m. on July 7. On July 30 it reached a maximum of 12.01 p. p. m. After this date it gradually decreases to 5.53 p. p. m. on August 20. By September 19 the dissolved oxygen is up to 10.25 p. p. m. again. The maximum of 12.21 p. p. m. when the temperature was 21.1° C. is amply accounted for by the plankton data Table 6 and is discussed more fully in that connection. The relationship between dissolved oxygen and temperature is shown in Figure 2. The variations in dissolved oxygen are shown in Figure 2.

In pond C 2 the dissolved oxygen reached a minimum of 2.14 p. p. m. on July 7. Then it rose to a maximum of 11.97 p. p. m. on July 30. Ten days later it had dropped to 2.59 p. p. m. On September 19 it was up to 8.18 p. p. m. The two minimal values for dissolved oxygen are associated with decreases in the loss on ignition and the volume of net plankton. Figure 2 shows the relationship between dissolved oxygen and temperature. The variations in dissolved oxygen are shown in Figure 2.

Table 3 shows that the dissolved oxygen in C 3 behaved somewhat differently than it did in C 1 and C 2. In this pond the minimum of 1.66 p. p. m. occurred simultaneously with a considerable increase in the net loss on ignition. Also the midsummer maximum of 6.91 p. p. m. is correlated with a sharp decline in the net loss on ignition. In C 1 and C 2 the reverse of this is true. The maximum for the season occurred on September 19 and amounted to 9.67 p. p. m. Figure 3 shows the variations in dissolved oxygen.

In C 4 the dissolved oxygen, as shown in Table 3, amounted to 6.29 p. p.m. on June 27. This figure is much higher than the corresponding figure for the other ponds of this series. The minimum of 3.53 p. p. m. is likewise higher than the minimum for C 1, C 2, and C 3. Both the season's minimum and the midsummer maximum are correlated with a decrease in the amount of organic matter. The amount of dissolved oxygen in C 1 and C 4 parallel each other fairly closely and are on the average somewhat higher than those in C 2 and C 3. The lower values for dissolved oxygen in C 2 and C 3 as compared with those in C 1 and C 4 are correlated with higher values for the average amount of organic matter. The variation in the dissolved oxygen in C 3 is shown in Figure 5.

Chlorides.—Table 3 shows that the amounts of chloride in solution in the water of C 1, C 2, and C 4 are comparable. The same is also true of their variations. In C 1 it ranges from 2.5 p. p. m. to 4.5 p. p. m. and the average for nine determinations is 2.94 p. p. m. In C 2 and C 4 it ranges from 2.0 p. p. m. to 3.5 p. p. m., but the average of nine determinations for C 2 is 2.7 p. p. m., while the average for an equal number of determinations in C 4 is 3.11 p. p. m.; that is, the unfertilized pond had on the average more chloride in solution than a pond fertilized with either superphosphate or soybean meal. In C 3 the amount of chloride in solution is much greater than that in C 1, C 2, and C 4. It ranges from 16.0 p. p. m. to 21.0 p. p. m. The average for nine determinations is 18.2 p. p. m. The higher values for dissolved chlorides in C 3 must be due to the type of fertilizers (shrimp bran) used. The fact that the average amount of chloride in C 1 and C 2 is less than that in C 4 probably does not mean that the superphosphate and the soybean meal contain no chloride, but rather that more chloride was consumed in the production of a relatively much larger crop of plankton. The variations in the dissolved chloride in C 1, C 2, C 3, and C 4 are shown in Figures 2 and 3, respectively. There is nothing in this chloride data that would point toward it as a limiting factor.

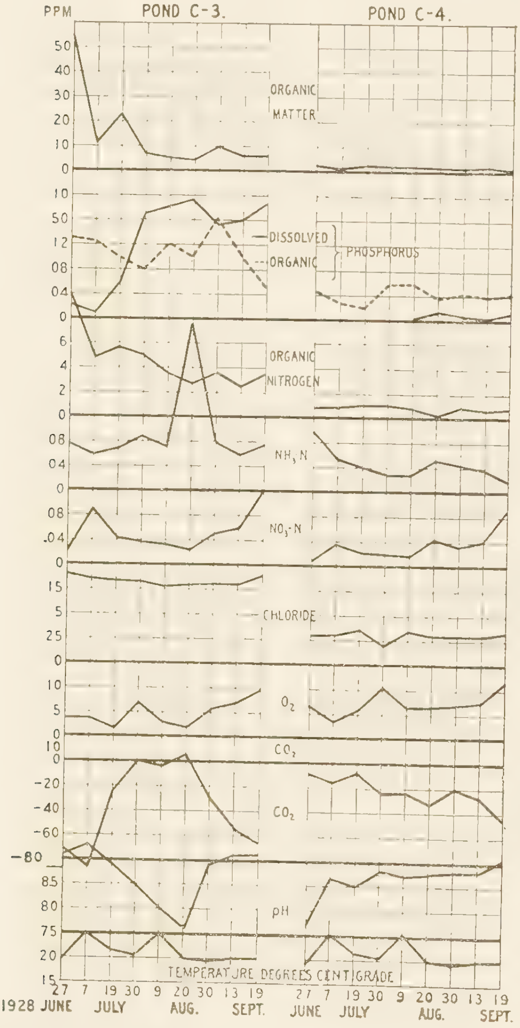

FIGURE 3.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for ponds C 3 and C 4

Nitrogen.—All the nitrogen data are combined in Table 4. The variations in the different forms of nitrogen are shown for C 1 in Figure 2, for C 2 in Figure 2, for C 3 in Figure 3, and for C 4 in Figure 3.

Nitrate nitrogen.—Table 4 shows that nitrate nitrogen in C 1 varied from a minimum of 0.008 p. p. m. at the beginning of the experiment to a maximum of 0.080 p. p. m. at the end of the experiment. In C 2 the minimum nitrate nitrogen of 0.032 p. p. m. occurred on August 9. The maximum of 0.150 p. p. m. was present on September 19. The minimum for the nitrate nitrogen corresponds to the maximum for ammonia nitrogen. Since this maximum for ammonia nitrogen occurs after a large decrease in the organic matter, the assumption seems warranted that this ammonia nitrogen is due rather to the bacterial decomposition of the organic matter than to the action of denitrifying bacteria. This conclusion seems justified also in view of the fact that there has not been a correspondingly large decrease in the nitrate nitrogen. The nitrogen as nitrate in C 3 is at a minimum of 0.023 p. p. m. and a maximum of 0.120 p. p. m. at the beginning and at the end of the experiment, respectively. In C 4 this form of nitrogen varied from a minimum of 0.009 p. p. m. to a maximum of 0.095 p. p. m. The minimum and the maximum occur here at the same time as the corresponding maxima and minima for C 1 and C 3. C 2 and C 3 contain on the average more nitrate nitrogen than C 1 and C 4. The average for nine determinations are: C 1, 0.036 p. p. m.; C 2, 0.059 p. p. m.; C 3, 0.053 p. p. m.; and C 4, 0.035 p. p. m. C 2 and C 4 differ from each other only by 0.001 p. p. m. and C 2 and C 3 differ from each other by 0.006 p. p. m. As in the case of the ammonia nitrogen the ponds fertilized with organic fertilizers yield the higher values for nitrogen.

Ammonia nitrogen.—Table 4 shows that in C 1 the ammonia nitrogen varied from a minimum of 0.012 p. p. m. to a maximum of 0.060 p. p. m. Except for the minimum value the variations are rather small; 0.044 p. p. m. to 0.060 p. p. m. In C 2 the ammonia nitrogen exhibits a far wider range of variations; namely, from 0.052 p. p. m. to 0.60 p. p. m. Only once does the ammonia nitrogen in C 1 equal that in C 2. The maximum for ammonia nitrogen in C 2 occurs simultaneously with a decrease in the net loss on ignition and the dissolved oxygen and an increase in the free CO_2. In C 3 the variation is from 0.060 p. p. m. (the maximum for C 1) to a maximum of 0.252 p. p. m. The maximum occurs here somewhat later than in C 1 and C 2, but is associated with similar changes in the net loss on ignition, dissolved oxygen, and free CO_2. In C 4 the maximum of 0.096 p. p. m. occurred on June 27 when the first observation was made. The minimum of 0.020 p. p. m. was present on September 19 when the last observation was made. Since the maximum occurs at the beginning of the experiment, it can not be determined whether or not it is associated with a decrease in organic matter.

The averages for nine determinations of ammonia nitrogen are as follows: C 1, 0.047 p. p. m.; C 2, 0.127 p. p. m.; C 3, 0.094 p. p. m.; and C 4, 0.044 p. p. m.

Organic nitrogen.—The results of organic nitrogen determinations show that this form of nitrogen varied in C 1 from a minimum of 0.608 p. p. m. to a maximum of 2.0 p. p. m. Figure 2 shows the variations in the organic nitrogen. In C 2 the organic nitrogen ranged from a minimum of 2.24 p. p. m. to a maximum of 6.43 p. p. m. For the variations in organic nitrogen see Figure 3. In C 3 the minimum was 2.56 p. p. m. and the maximum 10.08 p. p. m. The variations in the organic nitrogen are shown in Figure 4. This last maximum is the largest amount of organic nitrogen that was ever encountered in this series of ponds. It coincides with the appearance of the maximum amount of organic matter of 58.8 milligrams per liter; 55.80 milligrams of organic matter is not only the maximum for C 3 but the maximum for the series. In C 4 the organic nitrogen varied from a minimum of 0.240 p. p. m. to a maximum of 1.00 p. p. m. This pond has the smallest amount of organic nitrogen. It has also the smallest amount of organic matter. (Table 4.)

The average for nine determinations of organic nitrogen are: C 1, 1.304 p. p. m.; C 2, 4.43 p. p. m.; C 3, 4.403 p. p. m.; and C 4, 0.704 p. p. m. These values for organic nitrogen would represent the following amounts of proteins: 8.150 p. p. m., 27.687 p. p. m., 27.518 p. p. m., and 4.400 p. p. m. Nitrite nitrogen was never encountered in this series of ponds.

Phosphorus.—The data on phosphorous determinations in Table 5 show that the determinations of soluble phosphorus were begun earlier than the other determinations except the net plankton. In C 1 the dissolved phosphorus was 1.28 p. p. m. on June 19. On the 22d it was up to 1.50 p. p. m. and on June 27 it had increased to 1.80 p. p. m. This was the maximum for this pond. The rise in dissolved phosphorus from June 16 to 27 is undoubtedly due to a diffusion of the phosphorus of the superphosphate which had been added on June 7 and 16. After June 27 the soluble phosphorus decreased gradually until on August 6 only 0.045 p. p. m. was left. From August 6 there is an increase from 0.045 p. p. m. to 0.055 p. p. m. The big rise between August 9 and 20 is due in part to the addition of superphosphate (Table 1) and in part to the regeneration of dissolved phosphorus from the organic (fig. 2). On August 30 the dissolved phosphorus was lower than on August 20 in spite of the fact that some more superphosphate was added on August 25 and that the increase in the net loss on ignition had not been any greater than during the interval from August 9 to 20. The large increase in the organic phosphorus, however, suggests that more phosphorus had been used than would have been expected from the increase in the organic matter. The increase after August 30 occurs at the expense of the organic phosphorus. The first decline in dissolved phosphorus occurred simultaneously with an abundant growth of the blue-green alga, *Sphaerozyga*. This alga is attached to the bottoms and does not appear in the water samples on which the organic matter is determined. After this alga disappeared, the plankton and the organic matter increased and the soluble phosphorus decreased to a minimum. The dissolved phosphorus did not increase again until the organic matter decreased. A marked increase in dissolved phosphorus did not occur until after additional superphosphate had been added. The organic phosphorus remained uniformly low until after the first sharp decline in the amount of organic matter on August 9. The maximum of 0.50 p. p. m. occurred on August 30 and is correlated with a rise in organic matter and a decrease in the dissolved phosphorus. Two weeks later the organic phosphorus was down to 0.140 p. p. m. again, but the soluble phosphorus had increased from 0.550 to 0.960 p. p. m. The variations in the organic and the dissolved phosphorus are illustrated in Figure 2.

In C 2 the dissolved phosphorus ranged from none at all to as much as 0.096 p. p. m. Except for the maximum on August 20 and a near maximum value for August 30 the dissolved phosphorus was uniformly low. On several occasions no soluble phosphorus was present. The rise in August is largely, if not altogether, due to the addition of fertilizer. (Through an error on the part of an assistant, 5 ounces of superphosphate were added to this pond along with the soybean meal on August 14.) It is not likely that much of this increase had come from the decomposing plankton. (Fig. 2.) The organic phosphorus ranges from a minimum of 0.070 p. p. m. to a maximum of 0.410 p. p. m. Figure 2 gives little evidence that points toward the regeneration of dissolved phosphorus from the organic. The latter seems to accumulate gradually until the maximum is reached. There is nothing in the rest of the data to account for the decrease in the organic phosphorus between August 30 and September 13. (The assumption might be made that on August 30 a very considerable amount of organic matter, rich in phosphorus, was colloidally dispersed in such fine particles that the centrifuge did not remove it.)

In C 3 the dissolved phosphorous varied from a minimum of 0.005 p. p. m. on June 19 to a maximum of 0.90 p. p. m. on August 20. Table 5 and Figure 3 show that the lower values for the dissolved phosphorus correspond to the higher values for organic matter. The simultaneous rise in dissolved phosphorus and the organic matter between July 7 and 19 may be due either to the addition of fertilizer on July 11 or to the degeneration of organic phosphorus. The increase in soluble phosphorus between July 19 and August 9 must have come from the decaying organic matter. The decrease between August 20 and 30 is accompanied by increases in organic matter and in the organic phosphorus. As soon as the organic matter begins to decline the soluble phosphorus goes up again. The organic phosphorus ranges from a minimum of 0.050 p. p. m. to a maximum of 0.550 p. p. m. The minimum for organic phosphorus corresponds to the maximum for the soluble phosphorus. Figure 3 shows the variations in organic matter, the dissolved phosphorus, and the organic phosphorus. Some degree of relationship between the soluble phosphorus and the organic matter is suggested by Figure 3. Yet one could not draw the conclusion that the soluble phosphorus is the limiting factor, for at no time was it completely exhausted. Moreover, the accumulation of a very considerable amount of soluble phosphorus was not followed by a correspondingly large increase in the organic matter.

Table 5 shows that the dissolved phosphorus was, as a rule, rather low in C 4. Several times it was present only in traces. At other times it was absent altogether. The maximum of 0.012 p. p. m. occurred on August 20 and is correlated with a slight decrease in organic matter. The organic phosphorus varied from a minimum of 0.015 p. p. m. on July 19 to a maximum of 0.058 p. p. m. on July 30 and on August 9. The variations in the dissolved phosphorus and the organic phosphorus are shown in Figure 3.

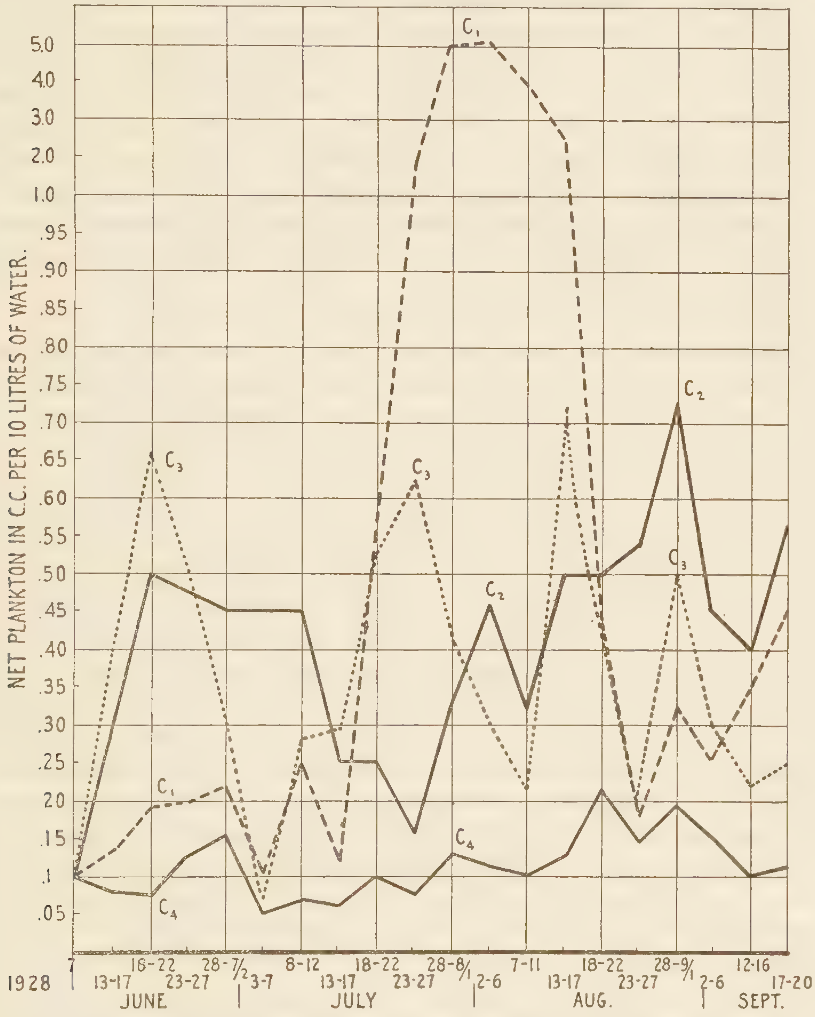

FIGURE 4.—The variation in the volume of net plankton in the C ponds

ORGANIC MATTER

The data on the organic matter in the centrifuge plankton are given in Table 4. This table shows that the organic matter in C 1 varied from a minimum of 1.35 milligrams per liter on July 19 to a maximum of 14.43 milligrams per liter of water on

September 13. The low values early in the season are associated with small numbers of algæ in the centrifuge plankton. (Table 8.) The increase in organic matter from July 19 to August 2 is due to a very rapid rise in the phytoplankton, due almost entirely to the growth of green algæ, especially the flagellates Pleodorina and Pandorina. Table 8 shows that on July 28 each liter of water contained 960,000 colonies of Pleodorina and on July 30 each liter of water contained 115,200 colonies of Pleodorina and 756,000 colonies of Pandorina. The net loss on ignition on July 30, August 2, and August 9 is not as great as might be expected from the volume of net plankton (Table 6), but this is probably due to the fact that the major portion of the net plankton was made up of hollow spherical colonies. From August 20 on the organic matter increases again, even though the volume of net plankton is far below the figure for the interval from July 31 to August 17. This is due to a change in the make up of the plankton. As Table 8 shows, the plankton is now dominated by the smaller algæ: Scenedesmus, Oocystis, Chroococcus, etc. The changes in the amount of organic matter are shown in Figure 2. The relationship of organic matter to phosphorus has already been discussed.

In C 2 the maximum amount of organic matter was found when the first determination was made on June 27. This maximum of 44.64 milligrams per liter of water is correlated with the maximum numbers for the algæ Scenedesmus and Aphanizomenon. (Table 8.) From June 27 to August 9 the tendency is downward except for the rise on July 30. This rise on July 30 occurs in spite of a decrease in the number of algæ. On August 9 the minimum of 5.19 milligrams per liter of water was reached. This minimum is correlated with the minimum for algæ counts. (Table 8.) The temporary rise on July 30 is accompanied by an increase in the dissolved oxygen from 6.76 to 11.97 p. p. m., an increase in pH from 8.7 to 9.0, and an increase in the alkalinity from 20.22 to 57.62 p. p. m. The large decrease in organic matter from 27.99 milligrams per liter on July 30 to 5.19 milligrams per liter on August 9 is accompanied by an increase in ammonia nitrogen (Table 4) from 0.144 to 0.60 p. p. m., a decrease in the dissolved oxygen from 11.97 to 2.59 p. p. m., and an increase in free CO_2 from -57.62 to 7.58 p. p. m., also a decrease in pH from 9.0 to 7.55. (Table 2.) There is also a slight increase in the dissolved phosphorus. (Fig. 2.) (The dissolved phosphorous was rather low until after the minimum for organic matter had been reached.) On August 20 the organic matter had increased to 24.74 milligrams per liter. The increase is accompanied by a large increase in the algæ Scenedesmus, Oocystis, and Chroococcus. (Table 8.) After August 20 the organic matter remained fairly constant until the end of the experiment. The variations in the organic matter are shown in Figure 2.

In C 3, as in C 2, the maximum for organic matter, namely, 55.80 milligrams per liter, occurred on June 27, when the first determination was made. This maximum is associated with the maximum number of algæ in the plankton. (Table 8.) After that the organic matter decreases very rapidly, so that on July 7 it is down to 11.41 milligrams per liter. Table 8 shows that the number of algæ in the plankton has also decreased enormously. This rapid decline in the organic matter is, however, not accompanied by an increase in the ammonia nitrogen, but there has been some increase in the nitrate nitrogen. (Fig. 3.) The dissolved oxygen has remained practically the same, and the alkalinity and the pH have increased. (Fig. 3.) All of which suggests that decomposition was not taking place at a very rapid rate and that the dead plankton had merely settled on the bottom. On July 19 the organic matter had increased to 23.30 milligrams per liter again. This rise is associated with large increases in the algæ Scenedesmus, Chroococcus, and Aphanizomenon. Still it is associated with a decrease in dissolved oxygen from 3.52 to 1.66 p. p. m., a slight increase in ammonia nitrogen, and a decrease in alkalinity from 85.94 to 23.42 p. p. m. The low oxygen and low alkalinity may be due to the fact that decomposition is going on more rapidly than photosynthesis. However, since there is a big increase in the algæ, it seems more logical to assume that the low oxygen and low alkalinity were due to the fact that during the night respiratory changes in the algæ had been using up the oxygen and at the same time produced the free CO_2 that reduced the alkalinity. Had the samples been taken at 3 p. m. instead of at 8 a. m., the dissolved oxygen and the alkalinity would probably both have been higher. After July 19 the organic matter is always relatively low. The minimum of 4.33 milligrams per liter was obtained on August 20. This minimum is accompanied by a low dissolved oxygen, 2.30 p. p. m.; a minimum pH value, 7.6; a maximum for free CO_2, 6.06 p. p. m.; and a maximum for soluble phosphorus of 0.90 p. p. m. The number of algæ, however, is not at a minimum on August 20. The rise in organic matter on August 30 is accompanied by big increases in the numbers of algæ Scenedesmus, Oocystis, and Chroococcus.

The amount of organic matter in the control pond, C 4, was on the average much lower than in the ponds C 1, C 2, and C 3. (Table 4.) The maximum of 2.51 milligrams per liter occurred on June 27. The minimum of 0.56 milligram per liter occurred on September 19, when the last determination was made. From July 19 to September 13 the amount of organic matter was practically stationary, ranging from 1.76 milligrams per liter to 1.5 milligrams per liter. Figure 3 shows that the dissolved phosphorus was also uniformly low and suggests that in this case the soluble phosphorus might have been a limiting factor. That inorganic nitrogen was not a limiting factor has been shown on pages 148 and 149. It is pointed out there that the average for ammonia nitrogen in C 1 was 0.047 and 0.044 p. p. m. for C 4, and that the average amount of nitrate nitrogen was 0.036 p. p. m. for C 1 and 0.035 p. p. m. for C 4. The low values for organic matter in C 4 are correlated with relatively small numbers of algæ. (Table 8.)

The average amount of organic matter present in 10 samples from C 1 was 7.22 milligrams per liter, the averages for 9 determinations for C 2, C 3, and C 4 were 23.86, 14.24, and 1.65 milligrams per liter, respectively.

PLANKTON

Net plankton.—The taking of net plankton samples was begun on June 7 and was continued until September 20. A total of 68 samples was taken from each pond. The dates on which samples were taken and the volumes of the samples are shown in Table 6. In Figure 4 the averages for 5-day intervals are plotted. These averages were obtained by dividing the sum of the volumes of plankton taken during the 5-day period by the number of samples taken during the period.

Table 6 shows that the net plankton in C 1 remained low until July 23, when suddenly it increased to 3.0 cubic centimeters per 10 liters of water. On August 1 the maximum of 9.0 cubic centimeters per 10 liters of water was reached. Then it dropped to 4.0 cubic centimeters per 10 liters of water on August 3 and 4, but on August 6 it was again up to 8.6 cubic centimeters per 10 liters of water. On August 18 it is down to less than a cubic centimeter per 10 liters of water, but on the average the volume of plankton after August 18 remains higher than it was before July 25. In the discussion of the free CO_2 (p. 145) it has already been pointed out that the enormous increase in the volume of net plankton during the latter part of July and the early part of August was due to the production in large numbers of the flagellates—Pleodorina and Pandorina. It has also been mentioned (p. 145) that the rise in the phytoplankton is associated with a high phenolphthalein alkalinity; namely, 68.76 p. p. m. at 8 a. m. on July 30 and of 72.80 p. p. m. at 3 p. m. on August 9. In discussing the dissolved oxygen it has been mentioned that the maximum of 12.21 p. p. m. occurred on July 30; that is, during the period when the net plankton ran high. Plankton counts show that on July 29 a liter of water contained 960,000 colonies of Pleodorina and on July 30, 115,200 colonies of Pleodorina and 756,000 colonies of Pandorina. (Table 8.) (The figures for the net plankton in this pond along with those for the phenolphthalein alkalinity and the dissolved oxygen give some idea as to the magnitude of the changes that may take place when everything is favorable for photosynthesis.) The average amount of net plankton for 68 samples was 1.22 cubic centimeters per 10 liters of water.

Table 6 shows that the behavior of the net plankton in C 2 was less striking than was the case in C 1. As the tables show the variation here was from 0.10 to 1.0 cubic centimeters per 10 liters of water, the total amount of net plankton produced in this pond is far less than that in C 1. The average for 68 samples from C 2 was 0.43 cubic centimeter; the average for an equal number of samples from C 1 was 1.22. This is a ratio of very nearly 1:2.3. This apparently contradicts the fact that the net loss on ignition in C 2 was slightly more than three times as large as that in C 1. However, it serves to emphasize the fact, already referred to in the introduction, that the volume of net plankton is not always an absolute standard whereby the productivity can be measured. This is well illustrated by the fact that even in C 1 the maximum for the net plankton does not correspond to the maximum for the loss on ignition. Again, on July 30, when the net plankton in C 1 and C 2 amounted to 3.5 and 0.48 cubic centimeters per 10 liters of water, respectively, the loss on ignition in C 1 was 3.69 milligrams per liter, and in C 2 it was 27.99 milligrams per liter of water. Plankton counts made on the centrifuge plankton of that date show that in C 1 each liter of water contained 115,200 colonies of Pleodorina and 756,600 colonies of Pandorina and that each liter of water in C 2 contained 40,200,000 filaments of Aphanizomenon and 480,000 filaments of Anabaena. The reason why the loss on ignition and the volume of net plankton do not always agree is due to the fact that the centrifuge removes small organisms and fine detritus that would pass through the net.

In pond C 3 the volume of net plankton varies from a minimum of 0.10 cubic centimeter per 10 liters of water to a maximum of 0.92 cubic centimeter per 10 liters of water. The average for 68 determinations was 0.36 cubic centimeter. The average amounts of net plankton for C 3 and C 2 do not differ very much. As Table 6 shows, there are brief intervals when the production in C 3 exceeds that in C 2, but on the average C 2 keeps somewhat ahead of C 3.

In control pond C 4 the volume of net plankton from 10 liters of water ranged from a minimum of 0.03 cubic centimeter to a maximum of 0.40 cubic centimeter. The average for 68 determinations was 0.12 cubic centimeter. This is exactly a third of the average for C 3, a little better than one-fourth the average for C 2 and approximately a tenth of the average for C 1. The same thing, therefore, that holds true for the organic matter is also true of the net plankton; namely, that the three ponds which were fertilized produced more plankton than did the control pond that was not fertilized.

In Table 7 there is given a brief summary of the results of enumerating the animals in the net plankton samples. Only the most important genera are listed. For a more complete tabulation of these results the reader is referred to another paper (Wiebe et al., 1929). The results show that Cyclops, Bosmina, the copepod nauplii, and the rotifers of the genus Anuraea were by far the most important constituents of the zooplankton. The table reveals a large discrepancy between the number of Cyclops and the number of nauplii. Since other copepods were present in very small numbers only, this discrepancy may be referred to as existing between nauplii and Cyclops. The table also shows that Anuraea was more abundant in the control pond

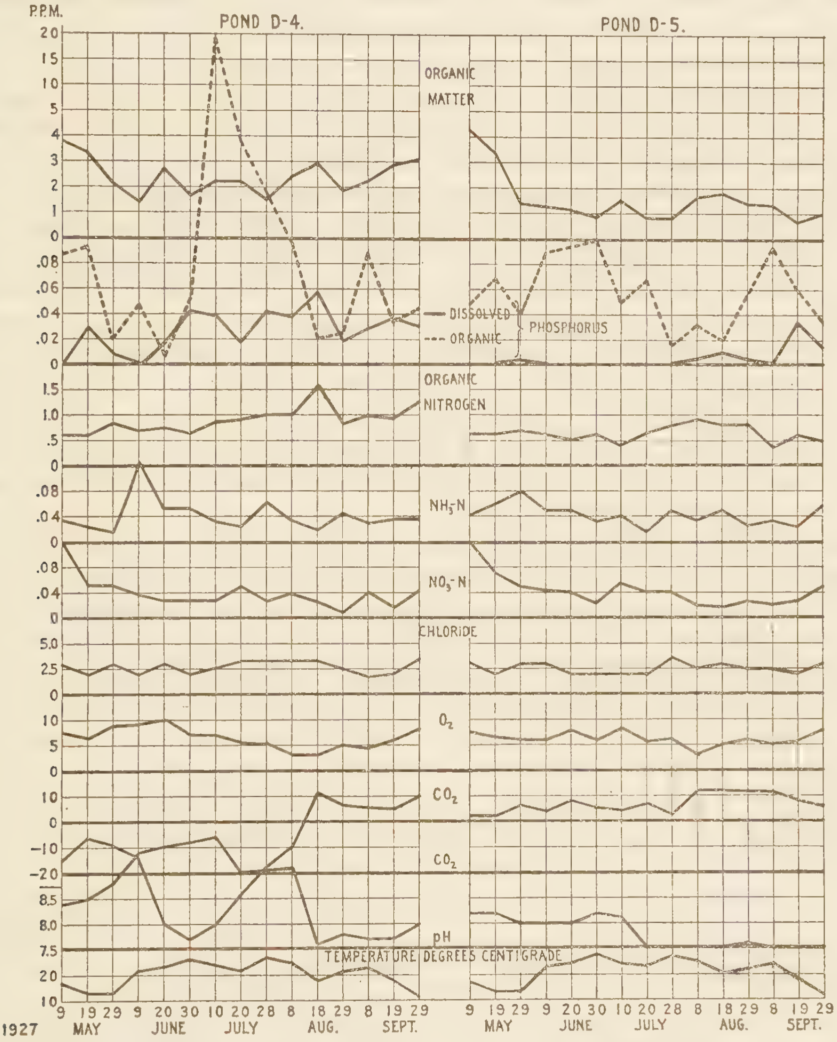

FIGURE 5.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for ponds D 4 and D 5

and in the pond that was fertilized with inorganic fertilizer than in those ponds that were fertilized with organic fertilizer.

The average number of all crustacea, exclusive of nauplii, per liter of water was as follows: C 1, 484.41; C 2, 1812.21; C 3, 621.4; and C 4, 265.72.

This brief summary of the zooplankton counts again shows quite definitely that the addition of fertilizer had a beneficial effect on plankton production.

Centrifuge plankton.—The algæ in the centrifuge plankton have been enumerated in all of the samples collected between June 27 and August 30, 1928. The results are tabulated in Tables 8 to 12.

C 1. Table 8 shows that Chroococcus was the only member of the Myxophyceæ that was present in large numbers. A maximum of 1,800,000 cells per liter occurred on August 30. Aphanizomenon was the only other blue-green alga that occurred in this pond. Among the Chlorophyceæ (exclusive of the flagellates) Oocystis, Pediastrum, Scenedesmus, and Staurastrum appeared in fairly large numbers. Oocystis reached a maximum on August 20, when 536,200 single cells and 960,000 colonies of this alga were present per liter of water. Pediastrum, Scenedesmus, and Staurastrum all reached a maximum on August 30. Of the flagellates, Pandorina and Pleodorina should be mentioned. These two colonial flagellates are the dominant forms in the plankton from July 28 to August 9. Pleodorina reaches a maximum of 960,000 colonies per liter on July 28 and Pandorina a maximum of 749,800 colonies on August 9. Eudorina and Volvox also occurred in the plankton, but only in small numbers. Stephanodiscus and Synedra were the only diatoms found in this pond and they occurred in small numbers only.

C 2. Table 8 shows that Aphanizomenon and Chroococcus were the principal Myxophyceæ that occurred in this pond. Of these the former reached a maximum of 205,500,000 filaments per liter on June 27, the latter a maximum of 8,032,000 single cells and 9,728,000 colonies on August 30. A third blue-green, Anabaena, occurred once in considerable numbers. The principal Chlorophyceæ were Oocystis and Scenedesmus. Both of these algæ attained a maximum on June 27, when each liter of water contained 240,000 single cells and 840,000 colonies of Oocystis and 8,550,000 colonies of Scenedesmus. Other green algæ present in appreciable numbers were Actinastrum, Closterium, Kirchneriella, Merismopedia, Pediastrum, and Tetrædron. Synedra was the only diatom that was found. The plankton of this pond was characterized by the total absence of the flagellates that were so abundant in C 1.

C 3. A comparison shows that the same algæ that were most abundant in C 2 are likewise the most abundant in C 3. Aphanizomenon reached a maximum of 101,700,000 on July 19. In the case of Chroococcus the single cells were most abundant on June 27, whereas the palmella stage was most abundant on August 30. Of the Chlorophyceæ, Oocystis reached a maximum of 1,219,720 single cells and 234,360 palmelloid colonies on August 30. The other leading green alga, Scenedesmus, attained a maximum of 3,840,000 colonies on June 27. It, however, was almost equally abundant on August 30. Other green algæ that occurred in considerable numbers were Actinastrum and Pediastrum. As in C 2, Synedra was the only diatom that occurred in the plankton from this pond. It was present in large numbers only once; namely, on June 27, when each liter of water contained 7,040,000 cells of this alga. The colonial flagellates that were so abundant in C 1 were absent altogether from the plankton of this pond.

C 4. Table 8 shows that the control pond, C 4, contained a greater variety of algæ than either C 2 or C 3, but that none of the algæ that were present in C 4 occurred in very large numbers. Scenedesmus was present in all but one sample from this pond, but the maximum number of colonies per liter of water was only 123,000. This is in marked contrast to the maxima for C 1, C 2, and C 3, as shown in Table 8. Single cells of Chroococcus occurred regularly, but here again the maximum was only 210,000 cells per liter. Aphanizomenon was more abundant in C 4 than in C 1, but it was far less abundant than in C 2 and C 3. Oocystis was present in all samples except the first, but the numbers per liter are not comparable to those for C 2 and C 3. The rest of the algæ that were found were present in small numbers only. It may be mentioned here that Eudorina occurred once in this pond. This is the only instance in which colonial flagellates were found in this series of ponds, outside of C 1.

In Table 9 there is given a summary of the dominant algæ in the centrifuge plankton for the four C ponds. This table shows a marked contrast in the abundance of algæ in the fertilized ponds as compared with their abundance in the control pond. It emphasizes, likewise, the difference in the types of algæ that are dominant in C 2, C 3, and C 4, and those that are dominant in C 1. The table shows that the dominant algæ in C 1 were colonial flagellates, whereas the dominant algæ in the other three ponds were the blue-greens, Aphanizomenon and Chroococcus; the greens, Oocystis and Scenedesmus; and the diatom, Synedra.

The relationship between the fluctuations in the number of algæ and the amount of organic matter has been referred to in the discussion of the latter.

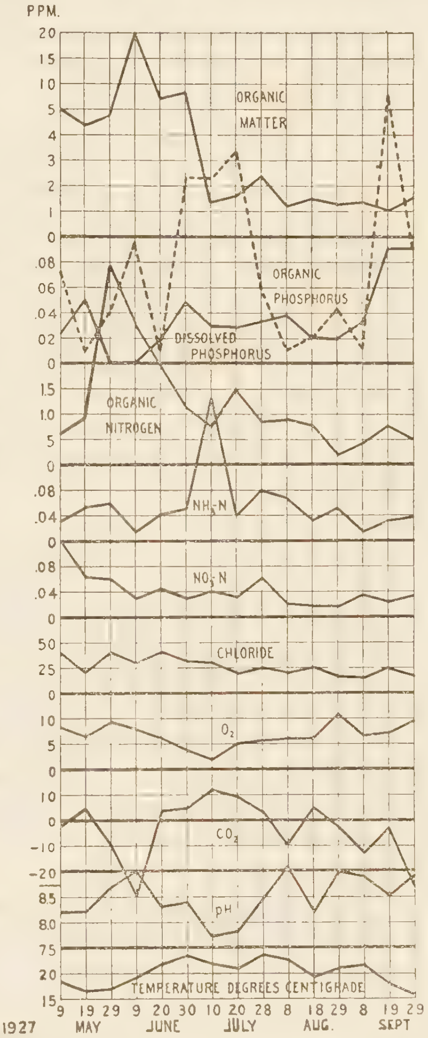

FIGURE 6.—Variations in free carbon dioxide, dissolved oxygen, chloride, different forms of nitrogen and phosphorus, and organic matter expressed in p. p. m.; pH values and temperatures in degrees C. for pond D 9

SUMMARY

It was stated at the beginning of this section that the object of the experiments in the C ponds was to determine the effectiveness of soybean meal, shrimp bran, and superphosphate as pond fertilizers. The results, as presented in Tables 4, 6, 8, and 9, show that each one of these fertilizers had a beneficial effect on plankton production. This is evidenced by the larger amount of organic matter in the centrifuge plankton, the larger volume of net plankton, and the greater number of algæ in the centrifuge plankton from the fertilized ponds as compared with the control pond. Which one of the three fertilizers used was the most effective it is difficult to say. The amount of organic matter and the number of algæ in the centrifuge plankton would rank the fertilizers in the following order: First, soybean meal; second, shrimp bran; and third, superphosphate. On the other hand, if the volume of net plankton is used the order would be: First, superphosphate; second, soybean meal; and third, shrimp bran. It has already been mentioned that the volume of net plankton is not an absolute index of productivity. This fact taken into consideration along with the data given in the tables, seems to warrant the conclusion that soybean meal was the most effective fertilizer.

D POND EXPERIMENTS

DESCRIPTION OF PONDS

The D ponds studied in this investigation constitute Nos. 4, 5, and 9, of a series of 10 dirt ponds. The position and the shape of these ponds are shown in chart 1. D 4 has an area of approximately 42,920 square feet, or 0.99 acre. Its maximum depth is 4.35 feet and it average depth is 2.47 feet. That gives the pond a volume of approximately 106,012 cubic feet. D 5 has practically the same area as D 4, namely, 42,860 square feet, or 0.98 acre. Its maximum depth is 4.5 feet and its average depth 2.21 feet. The volume of this pond is, therefore, approximately 94,720 cubic feet. D 9 has an area considerably smaller than either D 4 or D 5. Its area equals 29,700 square feet, or 0.66 acre. Its maximum depth is 4.8 feet and its average depth is 3.61 feet. This gives the pond a volume of 107,217 cubic feet.

PURPOSE OF THIS EXPERIMENT

The object of the limnological observation on the D ponds was to determine the behavior of the plankton, the phosphorus, the carbon dioxide, dissolved oxygen, hydrogen-ion, chlorides, and the different forms of nitrogen in dirt ponds in which fish were being raised. The effect of fertilizer was also considered. (See below.)

The observations on the D ponds cover the period from May 9, 1927, to September 29 of the same year. The observations were made at approximately 10-day intervals. All samples were taken from the surface. All samples were taken between 6.30 and 7.30 a. m.

POND D 4

This pond had been wintered wet. It was drained during the last week in April. On April 30 it was refilled with water and stocked with fish.

The pond was fertilized with a 3:1 mixture of sheep manure and superphosphate. On May 9 and June 18, 118 pounds of this mixture were added to the pond. Then from July 2 until August 23, 39 pounds of fertilizer were added every five days.

NOTES ON VEGETATION

May 15: Patches of cattails (*Typha latifolia*) along north bank.
May 26:
    Patches of cattails (*Typha latifolia*) along north bank.
    Blanket algæ (mostly Hydrodictyon) common.
June 16:
    Blanket algæ (mostly Hydrodictyon) cover 10 to 15 per cent of area (estimate).
    Elodea, common, covers about 10 per cent of area.
    Typha, cover about 5 per cent of area.
    Sagittaria, cover about 2 per cent of area.
    Various grasses, pond lilies and narrow-leafed Potamogeton present.

June 30:
  Blanket algæ (Hydrodictyon) covers about 20 per cent of area.
  Elodea cover about 15 per cent of area.
  Sagittaria cover about 3 per cent of area.
  Cattails (Typha) cover about 1 per cent of area.
  Narrow-leafed Potamogeton present.
July 23:
  Elodea cover about 10 per cent of area.
  Cattails (Typha) cover about 3 per cent of area.
  Sagittaria cover about 2 per cent of area.
  Blanket algæ cover about 5 per cent of area.
  Broad-leafed Potamogeton present.
August 16:
  Elodea cover about 10 per cent of area.
  Sagittaria cover about 2 per cent of area.
  Blanket algæ cover about 8 per cent of area.
  Cattails (Typha) cover about 1 per cent of area.

LIMNOLOGICAL DATA

Table 10 shows that the temperature was 17.2° C. on May 9, when the first observations were made. On May 19 the temperature had gone down to 13.3° C. The maximum temperature of 26.7° C. occurred on June 30 and July 28.

A study of Table 10 shows that the transparency of the water in D 4 was relatively high. Transparency, or the depth at which a 4-inch white disk disappears from view varied from 2 to 4 feet. The lower values for transparency were due to silt.

Table 10 shows that the minimum pH value of 7.6 occurred on August 18 and the maximum of 9.7 on July 10. Figure 5 shows that in a measure the higher pH values correspond to the higher temperatures. The correlation, however, is not close enough to warrant the conclusion that the hydrogen-ion concentration varies inversely as the temperature.

Free CO_2 did not occur in this pond until August 18, when 12.64 p. p. m. of the gas were present. This is the maximum of free CO_2 observed in this pond. After August 18 free CO_2 was present regularly. From May 9 to August 8 the water always showed a free CO_2 deficiency or a phenolphthalein alkalinity. This alkalinity ranged from a minimum of 6.08 p. p. m. on May 19 to a maximum of 46.5 p. p. m. on June 30. Table 10 shows that the maximum alkalinity corresponds to practically the maximum pH value. The variations in CO_2 are shown graphically in Figure 5.

The dissolved oxygen varied from a minimum of 2.86 p. p. m. on August 18 to a maximum of 10.46 p. p. m. on June 9. The low values for dissolved oxygen on August 8 and 18 are probably due to the decaying of blanket algæ. The notes on vegetation show that there had been a marked decrease in blanket algæ since June 20. Figure 5 shows the variations in dissolved oxygen.

The dissolved chlorides ranged from 1.8 to 3.5 p. p. m. There is no correlation between the variations in the chlorides and those in the organic matter that points toward the soluble chloride as a limiting factor. The variations in chlorides are shown in Table 10.

All nitrogen data are shown in Table 10. This table shows that the ammonia nitrogen varied from a minimum of 0.016 p. p. m. on May 29 to a maximum of 0.128 p. p. m. on June 9. This increase in ammonia nitrogen is associated with a decrease in organic matter. The decrease in ammonia nitrogen after June 9 is due to the growth of blanket algæ. The fact that there were 0.052 p. p. m. of ammonia nitrogen on June 30 is due to the addition of fertilizer. Nitrate nitrogen ranged from a maximum of 0.120 p. p. m. on May 9 to a minimum of 0.010 p. p. m. on August 29. On September 29 the nitrate nitrogen was up to 0.047 p. p. m. again. Nitrite nitrogen was present only once; namely, on September 29, when 0.002 p. p. m. was present. The organic nitrogen ranged from a minimum of 0.602 p. p. m. on May 19 to a maximum of 1.60 p. p. m. on August 18. This maximum value for organic nitrogen is probably due to the decomposition of blanket algæ. It occurs simultaneously with the minimum for dissolved oxygen and the maximum for free CO_2. Total nitrogen ranges from a minimum of 0.704 to 1.65 p. p. m. The variations in the different forms of nitrogen are shown in Figure 5.

Table 10 shows that on May 9, when the first observation was made, no dissolved phosphorus was present. After that date dissolved phosphorus was always present, although on June 9 it was down to a trace. After June 9 it was always present in considerable quantities. This is due, no doubt, to the addition of fertilizer at regular intervals. The organic phosphorus varied from a minimum of 0.005 milligram on June 20 to a maximum of 0.257 milligram on July 10. The variations in the soluble and the organic phosphorus are shown in Figure 5.

The organic matter or the net loss on ignition is rather uniform throughout the summer and is uniformly low. The minimum of 1.39 milligrams per liter occurred on June 9. This occurs simultaneously with the maximum for ammonia nitrogen. The maximum of 3.83 milligrams per liter occurred on May 9, when the soluble phosphorus was exhausted. On the whole, the relationship between the dissolved phosphorus and the organic matter is not very clear in this case. This is probably due to the fact that the pond was fertilized at short intervals and to the abundant growth of blanket algæ and rooted vegetation such as cattails and Elodea.

PLANKTON

Net plankton.—Table 10 shows that the volume of net plankton varied from a minimum of 0.05 cubic centimeter per 10 liters of water to a maximum of 0.45 cubic centimeter. The average for 15 determinations was 0.18 cubic centimeter per 10 liters. The animals in the net plankton have been enumerated. The results are here given very briefly. Cyclops was always present in appreciable numbers. The maximum of 177.0 individuals per liter occurred on June 9. Diaptomus occurred for the first time on August 29. It was present in all September samples. The maximum of 15 per liter occurred on September 29. Nauplii were always present. They reached their maximum development in the latter part of May and during June. The maximum of 1,245 nauplii per liter was found on June 9. Of the Cladocera occurring in the net plankton, Bosmina was the most common. It was present in all samples except in two of the May samples. Bosmina was most abundant during the last few days in June and during July. It was still fairly abundant during the greater part of August. A maximum of 975 Bosmina per liter was found on July 20. Ceriodaphuia was present in all samples except one after June 20. The maximum of 95.2 per liter occurred on August 29. Chydorus occurred regularly from May 9 to June 9. After that it occurred only twice and then in small numbers. The maximum of 37.8 per liter was found on May 29. Daphnia was present in small numbers from May 29 to June 20, and again on July 20, the maximum number being 9.0 per liter. Scapholeberis occurred once in small numbers. Moina occurred twice in very small numbers. Among the

Rotifera, Anuraea, Asplanchna, Brachionus, Polyarthra, and Triarthra were the most common. Anuraea was present in two-thirds of the samples and reached a maximum of 465.0 per liter on June 9. Asplanchna occurred only in one-third of the samples, but attained a maximum of 651 per liter on May 29. Brachionus occurred in three samples having a maximum of 25.5 per liter on May 19. Polyarthra was found regularly during June and September. It was present, also, in one sample for July and in one for August. The maximum of 65.2 individuals per liter occurred on June 30. Triarthra occurred three times—twice in May and once in June. The maximum number of 28.5 per liter occurred on May 19. The genera Monostyla, Rotifer, Noteus, and Rattulus were at different times represented by a few individuals.

Centrifuge plankton.—All the algæ in the centrifuge plankton have been enumerated, but only the principal ones are taken up here. The number of algæ, on the whole, is very low. Among the Myxophyceæ, Aphanizomenon was the most important one. But even it did not occur in anything like the numbers that are given below for D 9. The maximum for Aphanizomenon in D 4 is 14,400 filaments per liter. Of the Chlorophyceæ, Oocystis and Gloeocystis were by far the most abundant. Oocystis occurred in a majority of the samples, but only in relatively small numbers, the maximum being 10,400 cells per liter. This number was present on June 20. Synedra is the only diatom that occurred in considerable numbers. The maximum for this alga was 48,100 cells per liter. This number was present on May 9. None of the Peridiniæ occurred in significant numbers.

POND D 5

The pond D 5 had not been in use for several years and, therefore, was in a sense a new pond. It had been wintered dry and was not fertilized. The water was turned into this pond during the last week of April.

NOTES ON VEGETATION

May 15: Cattails (*Typha latifolia*) abundant all over the pond.
May 26: Cattails (*Typha latifolia*) abundant all over the pond.
June 16: Cattails covered approximately 80 per cent of area. Various grasses cover large area of bottom.
June 30: Cattails cover about 85 per cent of area. Land plant and spear grass present.
July 23: Cattails cover about 50 per cent of area. Elodea, blanket, algæ, land plants and grasses present.
August 16: Cattails cover about 60 per cent of area; grasses and land plants, 25 per cent of area. Some blanket algæ (Hydrodictyon).

LIMNOLOGICAL DATA

The limnological data are shown in Table 10.

The range in temperature is very similar to that recorded for D 4. The minimum spring temperature of 13.3° C. occurred on May 19. The maximum summer temperature of 27.8° C., occurred on June 30. By September 29 the temperature was down to 11.1° C.

A study of Table 10 shows that the water in pond D 5 was more transparent than in D 4 and D 9. The minimum transparency was 3 feet. When the transparency reached a maximum, the bottom was visible. The greater transparency of the water in this pond is due, at least in part, to the small amount of plankton.

The pH in this pond varied from a maximum of 8.2 to a minimum of 7.5. This minimum value was obtained 6 times in 14 determinations. Figure 5 shows these variations in pH.

Table 14 shows that free CO_2 was always present and varied from a minimum of 2.02 p. p. m. on May 19 to a maximum of 12.64 p. p. m. on August 8 and 18. The higher values for free CO_2 correspond, as a rule, to the lower pH values. (Table 10.) The variations are shown graphically in Figure 5.

The dissolved oxygen ranges from a maximum of 8.14 p. p. m. on July 10 to a minimum of 3.33 p. p. m. on August 8. This minimum for dissolved oxygen occurred on the same date as one of the maxima for free CO_2. The variations in the dissolved oxygen are shown in Figure 5.

Dissolved chloride was always present. Table 10 shows that it varied from 2.0 to 3.5 p. p. m. There is nothing in Table 10 that points toward chlorides as a limiting factor.

The data on nitrogen determinations are given in Table 10. The ammonia nitrogen reached a maximum of 0.080 p. p. m. on May 29. The minimum of 0.016 p. p. m. was reached on July 20. The nitrate nitrogen was at its highest point on May 9, when the first determination was made. At that time 0.120 p. p. m. was present. It decreased gradually until on June 30 only 0.025 p. p. m. was found. On July 10 it was up to 0.055 p. p. m. again. The minimum of 0.015 p. p. m. occurred on August 18. Figure 5 shows that at times the ammonia and the nitrate nitrogen increase or decrease simultaneously; at other times they vary in opposite direction. Nitrite nitrogen occurred only once; namely, on May 19, when 0.002 p. p. m. of this form of nitrogen were present. The organic nitrogen ranged from a minimum of 0.360 p. p. m. on September 9 to a maximum of 0.920 p. p. m. on August 8. Since most of the nitrogen present is in the form of organic nitrogen, the values for total nitrogen follow the values for organic nitrogen rather closely. The minimum for total nitrogen was 0.411 p. p. m., the maximum was 0.972 p. p. m.; and they occurred on the same dates, respectively, as the minimum and the maximum for organic nitrogen. The variations in the different forms of nitrogen are shown in Figure 8.

Table 10 shows that the dissolved phosphorus varied from none at all on May 9 to as much as 0.032 p. p. m. on September 19. The absence of soluble phosphorus on May 9 is correlated with the maximum amount of organic matter. The high values of 0.028 p. p. m. on July 7 and of 0.032 p. p. m. on September 19 are associated with a decrease in the organic matter and the organic phosphorus. (Fig. 5.) It may, therefore, be assumed that this soluble phosphorus had been derived from the organic phosphorus. The small amount of dissolved phosphorus present from May 29 to July 10, in spite of the small amount of organic matter, is perhaps due to the rapid growth of cattails. The notes on vegetation show that on June 30 the area estimated to be covered by cattails amounted to 85 per cent of the entire pond area. Organic phosphorus was always present in considerable quantities. It ranged from a minimum of 0.013 milligram per liter to a maximum of 0.095 milligram per liter of water.

The organic matter ranged from a minimum of 0.57 milligram per liter to a maximum of 4.24 milligrams per liter of water. The relationship of the organic matter to the soluble phosphorus has been discussed above.

The data presented here would seem to suggest that, at times, the dissolved phosphorus may have been a limiting factor that determined the productivity of the surface waters of this pond.

PLANKTON

Net plankton.—The net plankton was usually low. The maximum amount present in 10 liters of water was 0.25 cubic centimeter. The average for 15 determinations was 0.11 cubic centimeter per 10 liters of water. The zooplankton counts made on the net plankton samples are here summarized very briefly. Cyclops was present in all save 2 samples. The maximum of 64.7 individuals occurred on May 9. On the average Cyclops were most abundant in August. Diaptomus was present in small numbers 5.25 per liter on June 20. Then it was present regularly from July 28 to September 29. The maximum number per liter was 9.0. This number was present on August 29. Nauplii were always present. They were most abundant in August. The maximum of 142.5 per liter occurred on August 8. Bosmina was present fairly regularly. The maximum of 212.5 individuals per liter occurred on June 9. Ceriodaphnia was present at four different times, but only in very small numbers. Chydorous occurred in 1 sample each for the months of June, July, and August and in 2 samples in September. The maximum of 13.6 per liter was reached in June. From May 29 on, Daphnia occurred more or less regularly. The maximum of 115.5 individuals per liter occurred on May 29. Diaphanasoma was present several times, but only in very small numbers. Of the Rotifera, the genus Anuraea was always present. The maximum of 155.2 per liter occurred on June 20. Brachionus was present twice in small numbers. Asplanchna occurred in 5 samples, reaching a maximum of 33 per liter on May 29. Cathypna occurred at six different times in small numbers. Polyarthra was also present in 6 samples, the maximum of 11.4 per liter coming in September. Triarthra occurred twice in May and once in June. In the June sample 17.0 individuals per liter occurred. The genera Rotifer, Noteus, and Monostyla occurred each once in insignificant numbers.

Centrifuge plankton.—All the algæ in the centrifuge plankton have been enumerated, but only the numerically important ones are discussed here. Among the Myxophyceae, Aphanizomenon may be mentioned. This alga was present fairly regularly after June 9, but it never occurred in large numbers, the maximum being 16,400 filaments to the liter. This number occurred in the sample for July 20. These small numbers are in marked contrast to the large numbers for Aphanizomenon in D 9. Anabaena, which also was very abundant in D 9, was absent altogether from D 5. Of the Chlorophyceae, Gloeocystis and Pandorina may be mentioned. Gloeocystis occurred in insignificant numbers on June 20. On August 29 and September 8, 18,000 and 72,000 cells per liter, respectively, were present. Pandorina occurred in a majority of the samples after June 20. The maximum of 28,800 colonies per liter occurred on June 30. Synedra, the only diatom that needs to be mentioned, was present in relatively small numbers in all samples save one. The maximum of 104,400 cells per liter occurred on August 8. On May 9, 66,300 cells per liter were present. Of the Flagellata, Euglena was present in 6 samples. The maximum of 20,700 was found in the sample for August 8.

POND D 9

D 9 had been stocked with fish in the fall of 1926 and was not drained in the spring of 1927. Like D 4, it was fertilized with a 3:1 mixture of sheep manure and superphosphate. On April 26 and on June 17, 81 pounds of this mixture were added to the pond. Then from July 2 until August 23, 27 pounds were added at 5-day intervals.

NOTES ON VEGETATION

May 15:
  A few cattails along north side.
  Aphanizomenon approaching water bloom stage.
May 26: Cattails northwest corner. Some Elodea.
June 16:
  A few cattails along northwest corner.
  Some Elodea scattered. Ranunculus rare.
June 30:
  Elodea cover about 5 per cent of area.
  Blanket algæ cover about 25 per cent of area.
  Cattails present.
June 23:
  Elodea cover about 2 per cent of area.
  Blanket algæ cover about 2 per cent of area.
  Cattails present.
August 16: Blanket algæ cover about 25 per cent of area.

LIMNOLOGICAL DATA

The samples from D 9 were taken on the same days as those from D 4 and D 5 and at 10-day intervals. The limnological data are given in Table 10.

Table 10 shows that the temperature range in D 9 was practically the same as that in D 4 and D 5. The minimum temperature observed is that of 11.1° C. on September 29. The maximum of 27.2° C. occurred on June 30 and on July 28.

The transparency of the water in D 9 was lower than that in D 4 and D 5 until July 20. From July 28 on, however, it was more transparent than the water in D 4 and compared favorably with that in D 5. The minimum transparency of 6 inches on June 9 is due, at least, in part to the water bloom caused by the blue-green algæ Aphanizomenon and Anabaena. Table 10 shows that the organic matter on this date amounted to 20.24 milligrams per liter of water. Phytoplankton counts for that date show that there were present per liter of water 4,635,000 filaments of Aphanizomenon and 6,345,000 filaments of Anabaena.

The reaction of the water varied from a minimum pH of 7.7 to a maximum of 9.1. The pH values of 9.0 on June 9 and August 29 correspond to the second greatest and the greatest alkalinity, respectively. The low pH values of 7.7 and 7.8 on July 10 and 20, respectively, correspond to the disappearance of the blanket algæ from the surface and to a decrease in the organic matter from 8.57 milligrams per liter to 1.30 milligrams per liter. The variations in pH are shown in Figure 6.

Table 10 shows that free CO_2 was present in varying amounts on seven different dates. At other times there existed a phenolphthalein alkalinity. The free CO_2 reached a maximum of 12.64 p. p. m. on July 10. The maximum phenolphthalein alkalinity of 38.42 p. p. m. occurred on August 29. The maximum of 12.64 p. p. m. of free CO_2 corresponds to the minimum pH of 7.7. The latter, as has already been pointed out, corresponds to a decrease in the organic matter and the disappearance of the blanket algæ. The alkalinity of 30.34 p. p. m. on June 9 corresponds to the water-bloom stage of Aphanizomenon and Anabaena. The alkalinities of 38.42 and 28.32 on August 29 and September 29, respectively, correspond to an abundant growth of blanket algæ. (No formal observations on the vegetation were made after August 16, but blanket algæ and some vegetation had to be removed before the pond was drained.) The variations in free CO_2 are shown in Figure 6.

Table 10 shows that the dissolved oxygen ranged from a minimum of 2.17 p. p. m. to a maximum of 11.34 p. p. m. The low value of 3.63 p. p. m. on June 30 and of 2.17 p. p. m. on July 10 follow the disappearance of the water bloom caused by the blue-greens and the temporary disappearance of the blanket algæ from the surface. The minimum for dissolved oxygen occurs on the same date as the maxima for free CO_2 and the hydrogen-ion concentration. The high values for dissolved oxygen of 9.47 p. p. m. (91.0 per cent saturation) on May 29, 11.34 p. p. m. (129.0 per cent saturation) on August 29, and 9.75 p. p. m. (88.1 per cent saturation) on September 29, correspond to pH values of 8.7, 9.0, and 8.9, and to the phenolphthalein alkalinities of 10.12 p. p. m., 38.42 p. p. m., and 28.32 p. p. m., respectively. The high oxygen values for May 29 and September 29 are due to the lower temperatures of the water. The degree of saturation shows that the water was capable of absorbing still more oxygen from the atmosphere. The difference between the minimum and the maximum amounts of dissolved oxygen can not be explained on a temperature basis, for the temperature on July 10, when the minimum 2.17 p. p. m. (24.2 per cent saturation) occurred, was 23.9° C.; the temperature on August 29, when the maximum 11.34 p. p. m. (129.0 per cent saturation) occurred, was 22.2° C.—a difference in temperature of 1.7° C. but a difference of 104.8 per cent in the degree of saturation. It has already been mentioned that the minimum was associated with the disappearance of the water bloom and is, therefore, in all probability caused by a decay of organic matter. The maximum, since the water is 129 per cent saturated with oxygen may be the result of photosynthetic activity. The variations in dissolved oxygen are shown in Figure 6.

The amount of chloride in solution ranges from 1.5 p. p. m. to 4.0 p. p. m. (Table 10.) The generally lower values for chlorides during the latter part of the season, when the plankton was low is due, probably, to the abundant growth of blanket algæ already referred to. There is no evidence, however, that chloride is a limiting factor.

The results of the nitrogen determinations are given in Table 10. This table shows that the ammonia nitrogen varied from a minimum of 0.016 p. p. m. on June 9 and September 8 to a maximum of 0.224 p. p. m. on July 10. The minimum of 0.016 p. p. m. corresponds to the maximum for organic matter. The maximum of 0.224 p. p. m. is associated with a decrease in organic matter. The nitrate nitrogen ranged from 0.120 p. p. m. on May 9 to 0.015 p. p. m. on August 18 and 29. Nitrite nitrogen was never present even in traces. The organic nitrogen varied from a minimum of 0.169 p. p. m. on August 29 to a maximum of 3.92 p. p. m. on May 29. As Table 10 shows the maximum for organic nitrogen does not correspond to the maximum for organic matter. This discrepancy is probably due to the fact that the sample on May 29 was centrifuged only once, while that on June 9 was centrifuged twice. Plankton counts made on the May 29 sample show that every liter of water contained 3,025,000 filaments of Aphanizomenon and 4,680,000 filaments of Anabaena. Now Juday (1926) has pointed out the fact that by centrifuging the water once only a small proportion of Aphanizomenon is removed. Hence, it seems permissible to assume that the value for organic matter on May 29 as given in Table 10 is far below the true value. The total nitrogen follows the organic nitrogen very closely. The minimum for the total nitrogen is 0.235 p. p. m. and the maximum is 4.04 p. p. m. The maxima for the organic and the total nitrogen occur when the blue-green plankton algæ are at the height of production. The minima occur when the plankton algæ are at a minimum and the blanket alga, Hydrodictyon, is at its height of development. The variations in the different forms of nitrogen are shown in Figure 6.

Table 10 shows that on May 9 the dissolved phosphorus amounted to 0.023 p. p. m. On May 19 this had increased to 0.048 p. p. m. This increase might have taken place at the expense of the organic phosphorus, since the latter had decreased very considerably. On May 29, however, the dissolved phosphorus had disappeared completely. On June 9 a trace only was present. The rapid decline in the soluble phosphorus is accompanied with a rapid growth of plankton algæ. After June 9 dissolved phosphorus is present regularly. That is does not become exhausted in spite of the abundant growth of Hydrodictyon is due to the addition of fertilizer. The relatively large amount of dissolved phosphorus on September 9 and 29 is due, no doubt, to the decay of organic matter that had accumulated on the bottom during the summer. The organic phosphorus ranges from a minimum of 0.010 p. p. m. to a maximum of 0.205 p. p. m. If it had been possible to estimate quantitatively the amount of blanket algæ each time a sample of water was taken the variation in the organic phosphorus would become more intelligible. The variations in the phosphorus are shown in Figure 6.

Table 10 and Figure 6 show that the organic matter was relatively much more abundant during the early part of the season than later. (A comparison of Table 10 with the notes on vegetation seems to indicate that the blanket algæ are displacing the plankton algæ in the surface waters. They accomplish this by depriving the latter of sunlight.) A maximum of 20.24 milligrams per liter of organic matter was present on June 9. A minimum of 1.09 milligrams per liter occurred on September 19. It has already been pointed out that the maximum of 20.24 milligrams corresponds to very high counts for Aphanizomenon and Anabaena. It is also associated with a high degree of alkalinity as is evidenced by a pH of 9.0 and a phenolphthalein alkalinity of 30.34 p. p. m. The low value for organic matter in the centrifuge plankton during July, August, and September is due, perhaps, to the very abundant growth of Hydrodictyon and not to the exhaustion of either the soluble phosphorus or the inorganic nitrogen, for Table 10 shows that soluble phosphorus, ammonia nitrogen, and nitrate nitrogen were always present during these months. The variations in organic matter are shown in Figure 6.

That phosphorus may, temporarily, become a limiting factor when a pond is not fertilized is suggested by the disappearance of the soluble phosphorus as shown by the determinations for May 29 and June 9. That the disappearance of the dissolved phosphorus is correlated with a maximum production of blue-green algæ has already been referred to.

PLANKTON

Net plankton.—Table 10 shows that the volume of net plankton varied from 0.05 cubic centimeter to 0.92 cubic centimeter per 10 liters of water. Only the animals of the net plankton have been counted and the results are as follows: Cyclops was present throughout the entire season; the maximum of 52 per liter occurred in July. Diaptomus occurred for the first time on July 29 and after that date was present regularly with a maximum of 44 per liter occurring on August 8. Nauplii were always present except on September 29 and were most abundant in June with the maximum of 216 per liter occurring on June 9. The following Cladocera occurred in the net plankton: Bosmina, Ceriodaphnia, Chydorus, Daphnia, and Diaphanasoma. Of these Bosmina was the most abundant and was present in all the samples.

It was more abundant in June than during any other month, with the maximum of 904 individuals per liter occurring on June 9. Ceriodaphnia was present once in May, once in June, once in July, and once in August. In September it occurred in 2 samples. The maximum of 48 per liter occurred on September 29. Chydorus was present throughout May and September. It was present also in the first June sample and in one of the August samples. The maximum of 66 per liter occurred on June 9. Daphnia did not occur until June 9, but after that date it was always present save for the one exception on September 9. It was more abundant during July and August than during June and September. The maximum of 297.5 per liter occurred on August 18. Diaphanasoma occurred once in May and July. During June it was absent and during August and September it was always present. The maximum of 13 individuals per liter occurred on September 19. The Rotifers were represented by the following genera: Anuraea, Asplanchna, Brachionus, Cathypna, Polyarthra, Rotifer, and Triarthra. Of these Anuraea was present the greatest number of times. It was most abundant in May and June and was absent during September. The maximum number per liter was 134.2, which were found in the sample taken on May 29. Asplanchua occurred twice; namely, on May 9 and May 29. On this latter date 365.2 individuals per liter were present. Brachionus occurred once in small numbers. Cathypna was present in small numbers at three different times—in May, June, and in September. Polyarthra occurred regularly in May and in the first June sample, and after that it occurred in the August 29 samples. Thirty-three individuals per liter was the maximum for this genus. Rotifer was present in 4 samples scattered over the entire season. The maximum number per liter was only 1.7. Triarthra occurred in small numbers in 2 of the May samples. In the first June sample 38 individuals per liter were present, but it was absent from the rest of the samples.

Centrifuge plankton.—In the centrifuge plankton all the algæ have been enumerated, but only the genera that were fairly common will be mentioned here. Of the Myxophyceæ, Anabaena and Aphanizomenon deserve mention. Anabaena was present in the 3 samples from May 29 to June 30, inclusive. The numbers of filaments per liter present were as follows: May 29, 4,680,000; June 9, 6,345,000; and June 20, 3,600. Aphanizomenon made its first appearance on May 19, when 6,500 filaments per liter of water were present. On May 19 this number had risen to 3,025,000 and on June 9 to 4,635,000. On June 20 it was down to 396,000 per liter, but it rose again to 1,670,400 on June 30. After this date it occurred in small numbers only. Among the Chlorophyceæ, Gloeocystis, and Oocystis may be mentioned. Gloeocystis occurred in small numbers in 2 of the June samples. It was present regularly from July 20 to September 8, the maximum of 93,600 per liter occurring on the last-mentioned date. Oocystis was present to the extent of 252,000 individuals on May 29 and 409,600 on June 9. After that it occurred fairly regularly but only in insignificant numbers. Of the diatoms, Synedra is the only form that occurred with any degree of regularity and was most abundant during May, with the maximum of 122,200 cells per liter occurring on May 9. Of the Peridiniæ, the genus Ceratium was the most common. This form was, except for 1 sample, always present after the end of June. The maximum for Ceratium was 28,800 cells per liter and occurred on August 29.

SUMMARY OF D PONDS

The data for the D ponds recorded in the preceding pages show that in each of these 3 ponds there occurred at least one instance when the soluble phosphorus was completely exhausted. This fact would seem to point toward the soluble phosphorus as a limiting factor. However, since there was an abundance of soluble phosphorus in D 4 and D 9 after June 9, and still the organic matter and the plankton remained low, it becomes very apparent that some other factor besides the soluble phosphorus plays a part in limiting productivity. The data also show that inorganic nitrogen (free ammonia and nitrates) was never completely exhausted and that the amounts of inorganic nitrogen present in the water of the unfertilized pond D 5 compared favorably with the amounts of inorganic nitrogen in D 4 and D 9, which were fertilized. The data on organic matter and on the volume of net plankton show that D 4 and D 9, which were fertilized, were more productive than D 5, which was not fertilized. The differences in the productivity of D 4 and D 5 becomes much more apparent when the fish production is taken into consideration. D 4 produced much more fish than did D 5. The fish production will be considered in a separate report.

GENERAL SUMMARY AND CONCLUSIONS

The discussion in the preceding pages has been limited to the data obtained from the C ponds and the D ponds. A series of observations similar to those made on the C ponds in 1928 was made on the A series of cement ponds in 1927. Observations similar to those made on the D ponds in 1927 were made on F 1 and on the E ponds in 1927. The observations on the E ponds were repeated in 1928. The data obtained from the A and the E ponds in the main confirm the data obtained on the C ponds and the D ponds but are too voluminous to include in the present paper. The following conclusions apply to all series alike:

(1) Although temperature is a very important factor and may govern the seasonal distribution of plants and animals, it can not be considered as a limiting factor in the course of this experiment. The differences in the temperatures from the different ponds as shown in Tables 3 and 10 are too small to account for the differences in the amount of plankton.

(2) Transparency also did not act as a limiting factor in the surface water of these ponds.

(3) The data on pH determinations do not point toward the hydrogen-ion as a limiting factor. In fact, they rather suggest that the hydrogen-ion concentration is controlled by productivity; that is, in any one pond when photosynthesis is going on at a high rate the pH is high also. When the rate of photosynthesis decreases and the amount of CO_2 resulting from respiration or from the decomposition of organic matter exceeds the CO_2 used in photosynthesis, the pH is low. The data suggest also that the variations in the concentration of the hydrogen-ion are due largely, if not altogether, to the variations in the amount of free CO_2.

(4) If the algæ were dependent on the free CO_2 in the water only, then CO_2 might be considered a limiting factor, for free CO_2 was often absent from the surface waters of these ponds. The algæ, however, can make use of a large proportion of the CO_2 present as the half-bound CO_2. Juday (1911) reports that certain algæ used as much as 83 per cent of the half-bound CO_2. In the course of this investigation it was found that plankton algæ, principally Pandorina and Pleodorina,

used up as much as 92 per cent of the half-bound CO_2. The results show that the half-bound CO_2 (unpublished data) was never completely exhausted, although in the 3 p. m. sample from C 1 August 9 only 5.06 p. p. m. were left. This suggests the possibility that on unusually bright days the available CO_2 may temporarily become exhausted. The data on CO_2 show that this occurred very rarely, if ever. In D 5 free CO_2 was always present when samples were taken in the morning, yet the production in this pond was poor.

(5) Dissolved oxygen was probably not a limiting factor. In the ponds that had fish in them there was always enough oxygen to meet the requirements of these fish. In the C ponds the lowest value for dissolved oxygen was 1.66 p. p. m. This should have been sufficient to supply the respiratory needs of the plankton organisms. Moreover, this minimum value for oxygen occurred when the algæ were very abundant in that pond (C 3), and the dissolved oxygen was undoubtedly much higher during the day than it was in the morning when the samples were taken. (That the amount of dissolved oxygen varies during the day was shown by some observations made in 1928 on 3 of the D ponds. Samples were taken at 6 a. m. and again at 3 p. m. During this interval the amount of dissolved oxygen increased in D 3 from 6.0 to 8.6 p. p. m., in D 9 from 4.68 to 15.90 p. p. m., and in D 10 from 6.57 to 7.83 p. p. m. The increase in the amount of dissolved oxygen in these ponds was roughly proportional to the amount of algæ present. D 9 had a water bloom of Anabaena.)

(6) There is, on the whole, very little correlation in the variations in the dissolved chloride and the amount of organic matter in the centrifuge plankton. This, taken together with the fact that chloride was always present in relatively large quantities—that is, as compared with the quantities of inorganic nitrogen or dissolved phosphorus—suggest very strongly that there was at all times an adequate supply of chloride available. Whether the unusually high concentrations of dissolved chloride in C 3 had any detrimental effect has not been determined. The high counts for algæ (Table 8) would tend to show that as much as 21.0 p. p. m. of chloride did not have an inhibitory effect on the algæ.

(7) That inorganic nitrogen was not a limiting factor is shown by the fact that nitrogen as free ammonia and as nitrates was always present. Moreover, the amounts of nitrogen as free ammonia and as nitrates in the unfertilized ponds compared favorably, in most instances, with the amounts of these substances present in the fertilized ponds. In D 5, which was not fertilized, the average amount of free ammonia present equaled the average amount present in D 4. The average amount of nitrate nitrogen in D 5 exceeds that in D 4 and D 9, both of which were fertilized. The data for the C series show that the averages for free ammonia nitrogen and nitrate nitrogen in C 1 and C 4 differ but slightly. Yet C 1 produced 4.37 times as much centrifuge plankton as C 4 did.

(8) That the soluble phosphorus may be a limiting factor is shown by the data presented in this paper. In all of the D pond studies, as well as in F 1, C 2, and C 4, the soluble phosphorus became completely exhausted for short periods of time. That the soluble phosphorus is not the only limiting factor is suggested by the behavior of the C ponds. In C 1 the dissolved phosphorus never fell below 0.045 p. p. m. and in C 3 not below 0.005 p. p. m. Still plankton production dropped markedly at that point. Again, in C 3, a subsequent rise in the dissolved phosphorus was not followed by a proportionately large increase in the amount of organic

matter in the centrifuge plankton. The facts presented in this paper do show that Harvey's (1927) statement to the effect that the productivity of the sea depends only on the amount of available nitrates and phosphates does not apply to these fish ponds. The data on phosphorus are only partially in agreement with the conclusions arrived at by Atkins and which have been reviewed in the introduction. However, they are more nearly in agreement with Atkins's theory than with the results obtained by Juday et al. on the lakes of Wisconsin.

(9) That the addition of various fertilizers increases the production of plankton in a pond is shown by the data for the C ponds. (Tables 4, 6, and 8.) It is also shown by the fish production in the D and the E ponds (data to be published in a separate paper). The large number of algæ in C 1, C 2, and C 3, as compared with the small numbers for C 4, are in agreement with the results obtained by Jaernefelt (1926) and those of Von Alten (1919). Jaernefelt used various combinations of inorganic salts and cellulose in half barrels and in glass aquaria. Gaerder and Gran (1927) and Gran (1927) in cultural experiments with raw sea water at times obtained an increase in the production of algæ when either nitrates or phosphates or a mixture of the two were added to the culture flasks. At other times the increase in the number of algæ in the treated flasks was no greater than in the untreated flasks. Gran concludes that when no additional increase was obtained in the treated flasks "That the occurrence of nutritive salts at that time was not yet the limiting factor for the nourishment of algæ." If in the experiments reported here the dates on which the ponds were fertilized are placed on the curves for the organic matter, the result is that often there is no immediate response to the addition of fertilizer. At times the plankton will keep on decreasing through several applications of fertilizer. Finally, however, when the necessary nutrient materials have accumulated and the conditions are physiologically right, the plankton goes up. That the naturally occurring plankton maxima are augmented through the addition of fertilizer would seem to follow from the fact that the average amount of plankton produced is increased.

(10) The results on the C ponds show that the organic fertilizers, soybean meal, and shrimp bran, which in addition to containing phosphorus also contain large amounts of nitrogen, give better results than superphosphate which contains phosphorus mainly. This is contrary to the conclusion reached by Fisher (1924) and to which reference has been made in the introduction. It seems also to contradict the conclusion arrived at in (7) that inorganic nitrogen was not a limiting factor. This latter contradiction may, however, be more apparent than real. It may be that the soybean meal and the shrimp bran contain along with the nitrogen some other substance that makes a greater utilization of nitrogen possible. Allen and Nelson (1908–9), who tried to rear marine algæ in artificial sea water made up of highly purified salts, report that the algæ would not grow in this culture medium. When, however, extracts of ulva or of fish tissue were added to the artificial sea water good growths were obtained.

Whatever the explanation may be, the fact that the addition of fertilizers increases the productivity of fish ponds seems to be fairly well established.

TABLE 1.—*Dates in 1928 on which the C ponds were fertilized and the kind and amount in pounds of fertilizer used*

Pond	Fertilizer	June 7	June 16	June 11	August 14	August 25	September 14
C 1	Superphosphate	1	1	0	½	½	0
C 2	Soybean meal	3	3	1	1	1	2
C 3	Shrimp bran	3	3	1	1	1	2
C 4	Control	0	0	0	0	0	0

TABLE 2.—*Quantities of free CO_2 and phenolphthalein alkalinity in the C ponds in 1928 expressed in milligrams per liter of water. pH values are also given in this table*

Date and time	Free CO_2		Alkalinity				pH			
	C 2	C 3	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4
June 27, 8 a. m.			10.10	40.46	71.80	8.08	8.5	8.9	9.1	7.7
July 7, 8 a. m.			14.16	16.18	85.94	15.16	8.7	8.7	9.3	8.65
July 19, 8 a. m.			27.70	20.22	23.42	9.10	8.8	8.7	8.9	8.5
July 30, 8 a. m.		0	68.76	57.62		23.26	9.0	9.0	8.5	8.8
Aug. 9, 8 a. m.	7.58		44.50		5.06	24.26	8.9	7.55	8.0	8.7
Aug. 9, 3 p. m.			72.80	23.24	13.14	26.28	9.1	8.7	8.7	8.9
Aug. 20, 8 a. m.		6.06	35.40	1.12		32.36	8.8	8.5	7.6	8.75
Aug. 30, 8 a. m.	5.56		28.32		30.34	20.22	8.85	8.5	8.9	8.8
Sept. 13, 1 p. m.			25.28	24.26	55.60	27.30	8.8	8.75	9.1	8.8
Sept. 19, 12 m.			21.72	15.16	65.72	45.50	8.9	8.5	9.1	9.05

TABLE 3.—*Amounts of chlorides and of dissolved oxygen in the C ponds in 1928 in milligrams per liter. Also the temperatures in degrees centigrade*

Date	Chloride				Dissolved oxygen				Temperature all ponds
	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4	
June 27	3.0	2.0	21.0	3.0	4.36	3.90	3.53	6.29	18.3
July 7	2.5	3.0	19.0	3.0	3.43	2.14	3.52	3.53	25.0
July 19	2.5	2.5	18.0	3.5	6.62	6.76	1.66	5.79	23.8
July 30	3.0	2.5	18.0	2.0	12.21	11.87	6.91	10.80	21.1
Aug. 9	2.5	2.0	16.0	3.5	8.74	2.59	3.10	6.41	25.0
Aug. 20	2.5	3.0	16.5	3.0	5.53	4.55	2.30	6.51	20.5
Aug. 30	3.0	3.0	17.5	3.0	6.85	3.99	5.52	6.99	19.4
Sept. 13	3.0	2.8	17.0	3.0	6.81	6.61	7.12	7.59	20.0
Sept. 19	4.5	3.5	21.0	3.5	10.25	8.18	9.67	11.79	20.0

TABLE 4.—*Organic matter in centrifuge plankton and nitrogen in the C ponds in 1928. The results are stated in milligrams per liter of water*

Date	Organic matter				Organic nitrogen				NH_3—nitrogen				NO_3—nitrogen			
	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4
June 27	3.63	44.64	55.80	2.51	0.992	5.02	10.08	0.840	0.012	0.076	0.076	0.096	0.008	0.045	0.023	0.009
July 7	1.38	26.15	11.41	1.17	.608	6.04	4.80		.052	.068	.060	.052	.015	.055	.090	.035
July 19	1.35	21.81	23.30	2.45	.760	5.48	5.73	1.00	.052	.052	.068	.040	.017	.045	.045	.022
July 30	3.69	27.99	6.98	1.70	1.60	5.80	5.08	1.00	.044	.144	.088	.028	.029	.035	.036	.019
Aug. 2	10.70															
Aug. 9	6.47	5.19	4.86	1.76	2.00	2.76	3.56	.784	.060	.600	.072	.028	.020	.032	.032	.018
Aug. 20	8.02	24.74	4.33	1.53	1.88	6.43	2.76	.240	.048	.104	.272	.052	.037	.055	.024	.045
Aug. 30	9.86	23.34	9.80	1.65	1.66	2.24	3.60	.912	.052	.080	.076	.044	.035	.040	.050	.033
Sept. 13	14.43	18.89	5.96	1.50	1.36	3.12	2.56	.640	.052	.060	.060	.036	.060	.080	.060	.043
Sept. 19	12.75	22.02	5.75	0.56	1.64	3.04	3.52	.928	.052	.060	.076	.020	.080	.150	.120	.095
Av.	7.22	23.86	14.24	1.65	1.304	4.43	4.40	.704	.047	.127	.094	.044	.036	.059	.053	.035

TABLE 5.—*Data on phosphorous determinations in milligrams per liter of water in the C ponds in 1928*

Date	Total				Dissolved				Organic			
	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4	C 1	C 2	C 3	C 4
June 19					1. 28	Nil.	0. 005	Nil.				
June 22					1. 50	Nil.	. 010	Nil.				
June 27	1. 850	0. 095	0. 250	0. 045	1. 80	0. 025	. 025	Trace.	0. 050	0. 072	0. 225	0. 045
June 28					1. 60	. 010	. 025	Nil.				
July 7		. 120	. 170	. 025	1. 60	Nil.	. 008	Nil.		. 120	. 162	. 025
July 14					. 640	. 022	. 012	Trace.				
July 19	. 400	. 070	. 150	. 015	. 360	Trace.	. 055	Trace.	. 040	. 070	. 095	. 015
July 24					. 240	Nil.	. 220	Nil.				
July 25					. 165	Nil.	. 360	Nil.				
July 30	. 120	. 110	. 700	. 058	. 075	Trace.	. 620	Nil.	. 045	. 110	. 080	. 058
Aug. 2					. 050							
Aug. 3					. 048	Nil.	. 620	Nil.				
Aug. 6					. 045							
Aug. 9	. 225	. 175	. 880	. 058	. 055	. 015	. 750	Trace.	. 175	. 160	. 130	. 058
Aug. 20	. 880	. 280	. 960	. 045	. 80	. 096	. 900	0. 012	. 080	. 184	. 060	. 033
Aug. 30	1. 120	. 500	1. 00	. 045	. 550	. 090	. 450	. 003	. 570	. 410	. 550	. 042
Sept. 13	1. 10	. 150	. 620	. 038	. 960	. 020	. 520	Nil.	. 140	. 130	. 100	. 038
Sept. 19	. 900	. 128	. 900	. 050	. 850	. 003	. 850	. 010	. 050	. 125	. 050	. 040

TABLE 6.—*Net plankton in cubic centimeters per 10 liters of water in the C ponds in 1928*

Date	C 1	C 2	C 3	C 4	Date	C 1	C 2	C 3	C 4	Date	C 1	C 2	C 3	C 4
June 7	0. 10	0. 10	0. 10	0. 10	July 14	0. 05	0. 20	0. 25	0. 10	Aug. 17	1. 15	0. 60	0. 55	0. 10
June 13	. 12	. 20	. 35	. 10	July 16	. 25	. 27	. 30	. 03	Aug. 18	. 60	. 65	. 70	. 15
June 15	. 12	. 40	. 50	. 05	July 18	. 15	. 20	. 35	. 10	Aug. 20	. 40	. 70	. 35	. 30
June 16	. 15	. 30	. 35	. 10	July 19	. 03	. 12	. 60	. 10	Aug. 21	. 40	. 60	. 28	. 12
June 19	. 20	. 70	. 65	. 05	July 21	. 10	. 45	. 65	. 12	Aug. 22	. 35	. 70	. 32	. 30
June 20	. 20	. 40	. 40	. 05	July 23	. 35	. 18	. 60	. 10	Aug. 23	. 12	. 48	. 30	. 12
June 21	. 15	. 45	. 50	. 10	July 25	3. 00	. 15	. 65	. 07	Aug. 24	. 15	. 55	. 18	. 15
June 22	. 20	. 45	. 95	. 10	July 28	. 85	. 22	. 38	. 06	Aug. 27	. 25	. 55	. 28	. 12
June 23	. 35	. 43	. 41	. 12	July 30	3. 50	. 48	. 28	. 07	Aug. 28	. 20	1. 0	. 18	. 13
June 24	. 15	. 75	. 65	. 10	July 31	4. 0	. 40	. 40	. 25	Aug. 29	. 30	. 90	. 70	. 18
June 25	. 14	. 60	. 85	. 28	Aug. 1	9. 0	. 18	. 35	. 13	Aug. 30	. 33	. 63	. 55	. 22
June 26	. 18	. 32	. 35	. 15	Aug. 2	4. 4	. 45	. 40	. 08	Aug. 31	. 22	. 48	. 50	. 15
June 27	. 10	. 39	. 29	. 10	Aug. 3	4. 0	. 32	. 30	. 15	Sept. 1	. 50	. 60	. 50	. 30
June 28	. 18	. 70	. 50	. 40	Aug. 4	4. 0	. 40	. 30	. 12	Sept. 4	. 25	. 55	. 35	. 10
June 30	. 30	. 45	. 18	. 12	Aug. 6	8. 6	. 70	. 20	. 16	Sept. 5	. 25	. 40	. 35	. 18
July 2	. 20	. 30	. 15	. 05	Aug. 7	6. 8	. 28	. 20	. 18	Sept. 6	. 28	. 40	. 20	. 15
July 5	. 10	. 32	. 10	. 05	Aug. 8	3. 5	. 28	. 22	. 10	Sept. 14	. 40	. 45	. 25	. 10
July 6	. 10	. 40	. 03	. 05	Aug. 9	3. 8	. 30	. 18	. 10	Sept. 15	. 20	. 60	. 20	. 10
July 9	. 15	. 50	. 20	. 10	Aug. 10	2. 8	. 26	. 28	. 06	Sept. 16	. 35	. 40	. 22	. 10
July 10	. 10	. 50	. 10	. 05	Aug. 11	3. 2	. 48	. 28	. 04	Sept. 17	. 60	. 60	. 25	. 12
July 11	. 50	. 10	. 25	. 03	Aug. 13	2. 3	. 38	. 50	. 08	Sept. 19	. 40	. 60	. 20	. 10
July 12	. 30	. 30	. 60	. 10	Aug. 15	3. 7	. 30	. 92	. 10	Sept. 20	. 35	. 50	. 30	. 15
July 13	. 05	. 30	. 30	. 07	Aug. 16	2. 3	. 70	. 75	. 25					

TABLE 7.—*Animals in the net plankton in the C ponds in 1928*

Organism	Pond	Number of samples	Average number per liter	Organism	Pond	Number of samples	Average number per liter
Cyclops	C 1	68	70. 38	Ceriodaphnia	C 1	68	69. 61
	C 2	69	505. 14		C 2	69	5. 9
	C 3	70	503. 73		C 3	70	0. 76
	C 4	68	31. 53		C 4	68	13. 6
Bosmina	C 1	68	325. 19	Diaphanosoma	C 1	68	8. 06
	C 2	69	1, 216. 39		C 2	69	0. 54
	C 3	70	26. 36		C 3	70	0. 15
	C 4	68	208. 12		C 4	68	2. 01
Moina	C 1	68	4. 89	Nauplii	C 1	68	3, 649. 68
	C 2	69	80. 27		C 2	69	511. 16
	C 3	70	52. 30		C 3	70	493. 98
	C 4	68	7. 07		C 4	68	622. 95
Daphnia	C 1	68	4. 37	Anuraea	C 1	68	691. 17
	C 2	69	3. 65		C 2	69	92. 46
	C 3	70	37. 94		C 3	70	130. 18
	C 4	68	1. 30		C 4	68	277. 44

TABLE 8.—*Number of algæ per liter of water in the centrifuge plankton in the C ponds in 1928*

POND C 1

Organism	June 27	July 7	July 19	July 28	July 30	Aug. 9	Aug. 20	Aug. 30
Aphanizomenon	14, 000	9, 000	9, 000					
Botryococeus			9, 000					
Botryococeus, compound colony							32, 000	24, 000
Chroococcus, single		9, 000						1, 800, 000
Chroococcus, colony			22, 500					
Closteirum							6, 400	
Cosmarium		3, 000	9, 000				89, 600	
Eudorina				24, 000	21, 600	7, 200	12, 800	
Merismopedia							12, 800	
Oocystis, single			31, 500	36, 000	21, 600	93, 600	563, 200	1, 920, 000
Oocystis, colony							960, 000	
Pandorina			4, 500	24, 000	756, 000	748, 800		
Pediastrum			4, 500				76, 800	133, 000
Pleodorina				960, 000	115, 200	216, 000		
Scenedesmus			4, 500			7, 200	1, 843, 200	7, 680, 000
Staurastrum								170, 000
Stephanodiscus								24, 000
Synedra	14, 400						6, 400	
Tetraspora							12, 800	
Volvox				24, 000				

POND C 2

Organism	June 27	July 7	July 19	July 30	August 9	August 20	August 30
Aphanizomenon	205, 500, 000	11, 160, 000	58, 320, 000	40, 200, 000			
Actinastrum	120, 000						
Anabaena				480, 000			
Chroococcus, single	1, 140, 000	2, 999, 600	342, 000	48, 000	1, 178, 310	13, 888, 300	8, 032, 000
Chroococcus, colony		195, 300	54, 000		572, 880	3, 333, 120	9, 728, 000
Closterium							60, 000
Kirchneriella	60, 000						
Merismopedia		39, 060	36, 000				
Oocystis, single	240, 000	442, 680	90, 000	18, 000	91, 140	729, 120	720, 000
Oocystis, colony	840, 000						
Pediastrum	60, 000	13, 020	30, 000	6, 000	6, 510	34, 720	
Scenedesmus	8, 550, 000	546, 840	180, 000		39, 060	2, 430, 400	5, 568, 000
Synedra	540, 000	450, 000	540, 000				48, 000
Tetraedron		13, 020	18, 000			34, 720	96, 000

POND C 3

Aphanizomenon	48, 000, 000	252, 000	101, 700, 000	868, 050	693, 000	1, 368, 000	
Actinastrum				110, 670			
Chroococcus, single	17, 920, 000.	528, 000	4, 230, 000	225, 460	126, 000	126, 000	1, 236, 900
Chroococcus, colony				234, 360		9, 000	429, 660
Kirchneriella		36, 000			54, 500		
Merismopedia	24, 000						
Oocystis, single	48, 000	72, 000		91, 140	36, 000	126, 000	1, 219, 720
Oocystis, colony							234, 360
Pediastrum	192, 000			37, 550	13, 500	58, 500	13, 020
Scenedesmus	3, 840, 000	780, 000	1, 260, 000	313, 735	63, 000	337, 500	3, 176, 880
Synedra	7, 040, 000					18, 000	
Tetraedron		12, 000					13, 020

POND C 4

Aphanizomenon		24, 000	264, 000			6, 000	
Botryococcus			12, 000			6, 000	
Ceratium							3, 000
Chroococcus, single	13, 500	6, 000	126, 000	9, 000	30, 000	66, 000	210, 000
Cosmarium			9, 000				3, 000
Crucigenia			3, 000				
Eudorina				21, 000			
Fragilaria		3, 000	3, 000	3, 000		3, 000	
Melosira		3, 000	12, 000	3, 000			
Navicula		3, 000	12, 000				
Oocystis, single		3, 000	24, 000	3, 000	12, 000	9, 000	24, 000
Oocystis, colony			12, 000			3, 000	9, 000
Pediastrum			15, 000	3, 000		12, 000	9, 000
Periodinium			9, 000				
Scenedesmus		3, 000	123, 000	12, 000	3, 000	63, 000	78, 000
Staurastrum			3, 000	15, 000	3, 000		6, 000
Stephanodiscus	4, 500						
Synedra			3, 000				
Tetraedron						3, 000	

TABLE 9.—*Relative abundance in the different ponds of the C series in 1928 of the principal algæ in the centrifuge plankton*

Pond	Organism	June 27	July 7	July 19	July 28	July 30	Aug. 9	Aug. 20	Aug. 30
C 1	Scenedesmus			4, 500			7, 200	1, 843, 200	7, 680, 000
C 2		8, 550, 000	546, 840	180, 000			39, 060	2, 430, 400	5, 568, 000
C 3		3, 840, 000	780, 000	1, 260, 000		313, 735	63, 000	337, 500	3, 176, 880
C 4			3, 000	123, 000		12, 000	3, 000	63, 000	78, 000
C 1	Chroococcus, single cells		9, 000						1, 800, 000
C 2		1, 140, 000	2, 999, 600	342, 000		48, 000	1, 178, 310	13, 888, 300	8, 032, 000
C 3		17, 920, 000	528, 000	4, 230, 000		2, 252, 460	126, 000	126, 000	1, 236, 900
C 4		13, 500	6, 000	126, 000		9, 000	30, 000	66, 000	210, 000
C 1	Chroococcus, colony			22, 500					
C 2			195, 300	54, 000			572, 880	3, 333, 120	9, 728, 000
C 3						234, 360		9, 000	429, 660
C 1	Aphsizomenon	14, 000	9, 000	9, 000					
C 2		205, 500, 000	11, 160, 000	58, 320, 000		40, 200, 000			
C 3		48, 000, 000	252, 000	101, 700, 000		868, 050	693, 000	1, 368, 000	
C 4			24, 000	264, 000				6, 000	
C 1	Oocystis, single cells			31, 500	36, 000	21, 600	93, 600	563, 200	1, 920, 000
C 2		240, 000	442, 680	90, 000		18, 000	91, 140	729, 120	720, 000
C 3		48, 000	72, 000			91, 140	36, 000	126, 000	1, 219, 720
C 4			3, 000	24, 000		3, 000	12, 000	9, 000	24, 000
C 1	Oocystis, colony							960, 000	
C 2		840, 000							
C 3									234, 360
C 4				12, 000				3, 000	9, 000
C 1	Pleodorina				960, 000	115, 200	216, 000		
C 1	Pandorina			4, 500	24, 000	756, 000	748, 800		
C 1	Synedra	14, 400						6, 400	
C 2		540, 000	450, 000	540, 000					48, 000
C 3		7, 040, 000						18, 000	
C 4				3, 000					

NOTE.—On July 28 no samples were taken from C 2, C 3, and C 4.

TABLE 10.—*Data on carbon dioxide, dissolved oxygen, chloride, phosphorus, nitrogen, and organic matter in milligrams per liter in 1927. Temperatures in degrees centigrade, turbidity in inches, net plankton in cubic centimeters per 10 liters of water. Also pH values*

POND D 4

Date	Temperature	Turbidity	O_2	pH	CO_2 free	Chloride	Phosphorus			Nitrogen				Organic matter	Net plankton
							Total	Dissolved	Organic	NH_3	NO_3	NO_2	Organic		
May 9	17. 2	29	7. 42	8. 4	−15. 18	3. 0	0. 085	Nil.	0. 085	0. 032	0. 120	Nil.	0. 632	3. 83	0. 10
May 19	13. 3	30	6. 59	8. 5	−6. 08	2. 0	. 095	0. 030	. 092	. 025	. 050	Nil.	. 602	3. 32	. 04
May 29	13. 3	38	9. 18	8. 8	−9. 10	3. 0	. 027	. 008	. 019	. 016	. 050	Nil.	. 880	2 16	. 10
June 9	22. 2	46	9. 55	9. 4	−14. 16	2. 0	. 095	Trace.	. 095	. 128	. 035	Nil.	. 720	1. 39	. 45
June 20	24. 4	41	10. 46	9. 5	−40. 44	3. 0	. 023	. 018	. 005	. 052	. 030	Nil.	. 768	2. 68	. 12
June 30	26. 7	48	7. 22	9. 6	−46. 52	2. 0	. 095	. 043	. 052	. 052	. 030	Nil.	. 664	1. 65	. 28
July 10	23. 9	28	7. 05	9. 7	−40. 44	2. 5	. 295	. 038	. 257	. 032	. 030	Nil.	. 856	2. 21	. 16
July 20	21. 7	32	5. 37	9. 0	−28. 32	3. 3	. 195	. 018	. 177	. 024	. 050	Nil.	. 912	2. 17	. 50
July 28	26. 7	29	5. 50		−18. 20	3. 3		. 043		. 064	. 030	Nil.	1. 024	1. 49	. 10
Aug. 8	25. 0	24	3. 43	9. 1	−10. 10	3. 3	. 135	. 038	. 097	. 032	. 040	Nil.	1. 024	2. 39	. 12
Aug. 18	18. 2	28	2. 86	7. 6	12. 64	3. 3	. 078	. 058	. 020	. 020	. 030	Nil.	1. 600	2. 88	. 15
Aug. 29	21. 7	30	5. 19	7. 8	6. 56	2. 5	. 068	. 018	. 050	. 044	. 010	Nil.	. 880	1. 81	. 20
Sept. 8	23. 3	24	4. 70	7. 7	5. 56	1. 8	. 115	. 028	. 087	. 032	. 042	Nil.	1. 080	2. 22	. 10
Sept. 19	16. 7	24	5. 86	7. 7	5. 16	2. 0	. 073	. 038	. 035	. 036	. 017	Nil.	. 960	2. 83	. 05
Sept. 29	11. 1	27	8. 21	8. 0	10. 10	3. 5	. 073	. 030	. 043	. 036	. 047	0. 002	1. 260	3. 07	. 30
Average										. 041	. 033		. 924	2. 41	. 18
POND D 5															
May 9	17. 22	41	7. 79	8. 2	2. 12	3. 0	0. 048	Nil.	0. 048	0. 038	0. 120	Nil.	0. 632	4. 24	0. 20
May 19	13. 3	48	6. 49	8. 2	2. 02	2. 0	. 067	Trace.	. 067	. 060	. 070	0. 002	. 601	3. 33	. 05
May 29	13. 9	60	6. 23	8. 0	6. 59	3. 0	. 039	0. 003	. 036	. 080	. 050	Nil.	. 720	1. 31	. 25
June 9	22. 8	46	6. 31	8. 0	4. 04	3. 0	. 086	Nil.	. 086	. 048		Nil.		1. 24	. 15
June 20	24. 4	50	7. 84	8. 0	8. 08	2. 0		Nil.		. 048	. 040	Nil.	. 528	1. 10	. 09
June 30	27. 8	53	6. 05	8. 2	5. 06	2. 0	. 095	Trace.	. 095	. 032	. 025	Nil.	. 600	. 83	. 06
July 10	24. 4	51	8. 14	8. 1	4. 56	2. 0	. 048	Trace.	. 048	. 040	. 055	Nil.	. 424	1. 46	. 05
July 20	22. 8	48	5. 35	7. 5	7. 08	2. 0	. 095	. 028	. 067	. 016	. 040	Nil.	. 672	. 77	. 04
July 28	26. 7	41	6. 07		3. 54	3. 5	. 013	Trace.	. 013	. 048	. 040	Nil.	. 864	. 79	. 07
Aug. 8	25. 0	36	3. 33	7. 5	12. 64	2. 5	. 038	. 008	. 030	. 032	. 020	Nil.	. 920	1. 58	. 15
Aug. 18	18. 9	41	5. 22	7. 5	12. 64	3. 0	. 028	. 010	. 018	. 048	. 015	Nil.	. 800	1. 73	. 20
Aug. 29	22. 2	48	6. 28	7. 6	11. 12	2. 5	. 058	. 003	. 055	. 024	. 025	Nil.	. 800	1. 30	. 10
Sept. 8	23. 3	54	5. 18	7. 5	11. 12	2. 5	. 095	Trace.	. 095	. 032	. 019	Nil.	. 360	1. 24	. 05
Sept. 19	17. 22	60	5. 65	7. 5	7. 58	2. 0	. 090	. 032	. 058	. 024	. 027	Nil.	. 600	. 57	. 10
Sept. 29	11. 1	60	7. 86	7. 5	6. 06	3. 0	. 043	. 013	. 030	. 060	. 050	Nil.	. 460	. 96	. 15
Average										. 041	. 042		. 641	1. 41	. 11

TABLE 10.—*Data on carbon dioxide, dissolved oxygen, chloride, phosphorus, nitrogen, and organic matter in milligrams per liter in 1927. Temperatures in degrees centigrade, turbidity in inches, net plankton in cubic centimeters per 10 liters of water. Also pH values*—Continued

POND D 9

Date	Temperature	Turbidity	O_2	pH	CO_2 free	Chloride	Phosphorus			Nitrogen				Organic matter	Net plankton
							Total	Dissolved	Organic	NH_3	NO_3	NO_2	Organic		
May 9	17.2	24	7.89	8.2	−2.02	4.0	0.095	0.023	0.072	0.032	0.120	Nil.	0.632	5.0	0.15
May 19	13.3	22	6.81	8.2	5.06	2.0	.058	.048	.010	.052	.060	Nil.	.900	4.44	.05
May 29	13.9	12	9.47	8.7	−10.12	4.0	.038	Nil.	.038	.060	.060	Nil.	3.920	4.76	.60
June 9	18.3	6	7.96	9.0	−30.34	3.0	.095	Trace.	.095	.016	.030	Nil.	2.760	20.24	.65
June 20	24.4	12	6.26	8.3	4.54	4.0	.028	.018	.010	.044	.045	Nil.	-------	7.02	.19
June 30	27.2	24	3.63	8.4	5.06	3.0	.195	.048	.147	.048	.030	Nil.	1.120	8.57	.29
July 10	23.9	24	2.17	7.7	12.64	3.0	.175	.029	.146	.224	.040	Nil.	.776	1.30	.08
July 20	21.7	40	5.16	7.8	9.78	2.0	.195	.029	.166	.040	.030	Nil.	1,472	1.57	.52
July 28	27.2	Bottom.	5.66	------	3.54	2.5	.095	.033	.062	.080	.060	Nil.	.864	2.30	.70
Aug. 8	25.5	Bottom.	6.22	9.1	−10.10	2.0	.048	.038	.010	.064	.020	Nil.	.920	1.24	.22
Aug. 18	19.4	Bottom.	5.76	8.2	5.06	2.5	.038	.019	.019	.032	.015	Nil.	.760	1.45	.92
Aug. 29	22.2	40	11.34	9.0	−3.42	1.5	.063	.018	.045	.052	.015	Nil.	.169	1.19	.12
Sept. 8	22.8	Bottom.	6.75	8.9	−13.16	1.5	.043	.033	.010	.016	.035	Nil.	.400	1.28	.15
Sept. 19	15.5	Bottom.	7.06	8.5	−3.04	2.5	.295	.090	.205	.032	.025	Nil.	.760	1.09	.20
Sept. 29	11.1	Bottom.	9.75	8.9	−28.32	1.5	.180	.090	.090	.036	.033	Nil.	.460	1.52	.60
Average	------	----------	------	------	--------	------	-------	--------	-------	.055	.041	-------	1.136	4.13	.36

NOTE.—A negative value for free CO_2 means a phenolphthalein alkalinity.

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SALMON-TAGGING EXPERIMENTS IN ALASKA, 1929[1]

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INTRODUCTION

The extensive salmon-tagging experiments which have been conducted in Alaska since 1922 were continued during 1929 in central Alaska, under the general direction of Dr. Willis H. Rich. The investigation was intended to determine the direction of migration from the entrances of Cook Inlet and Prince William Sound, and from prominent points by which the fish pass to reach the spawning grounds of those regions. The method of tagging has been adequately described in previous reports.[2]

Because those areas are comparatively small and the fish entering them are largely bound for local spawning grounds, it seemed unnecessary to tag a very great number of salmon. An effort was made, however, to conduct the operations early in the season and again during the height and toward the end of the run, to determine whether the migration and distribution of the fish varied during the season.

The accompanying map will serve to show the general geography of central Alaska; and the following list includes all minor localities from which tagged fish were recorded.

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[1] Submitted for publication Apr. 1, 1930.

[2] "Experiments in tagging adult red salmon, Alaska Peninsula Fisheries Reservation, summer of 1922," by Charles H. Gilbert. Bulletin, U. S. Bureau of Fisheries, Vol. XXXIX, 1923–24, (1924), pp. 39–50, 1 fig., Washington. "Second experiment in tagging salmon in the Alaska Peninsula Fisheries Reservation, summer of 1923," by Charles H. Gilbert and Willis H. Rich. *Ibid.*, Vol. XLII, 1926 (1927), pp. 27–75, 12 figs., Washington. "Salmon-tagging experiments in Alaska, 1924 and 1925," by Willis H. Rich. *Ibid.*, pp. 109–146, 1 fig., Washington, 1926. "Salmon-tagging experiments in Alaska, 1926," by Willis H. Rich and Arnie J. Suomela. *Ibid.*, Vol. XLIII, 1927, Pt. II (1929), pp. 71–104, 17 figs., Washington, 1927. "Salmon-tagging experiments in Alaska, 1927 and 1928," by Willis H. Rich and Frederick G. Morton. *Ibid.*, Vol. XLV, 1929, pp. 1–23, 2 figs., Washington, 1929.

SUPPLEMENTARY LIST OF MINOR LOCALITIES FROM WHICH TAGGED SALMON WERE RECORDED

PRINCE WILLIAM SOUND

Anderson Bay. Hinchinbrook Island, 4 miles east of Johnstone Point.
Bainbridge Passage. Between Bainbridge Island and the mainland.
Bay of Isles. East shore of Knight Island, 17 miles north of Point Helen.

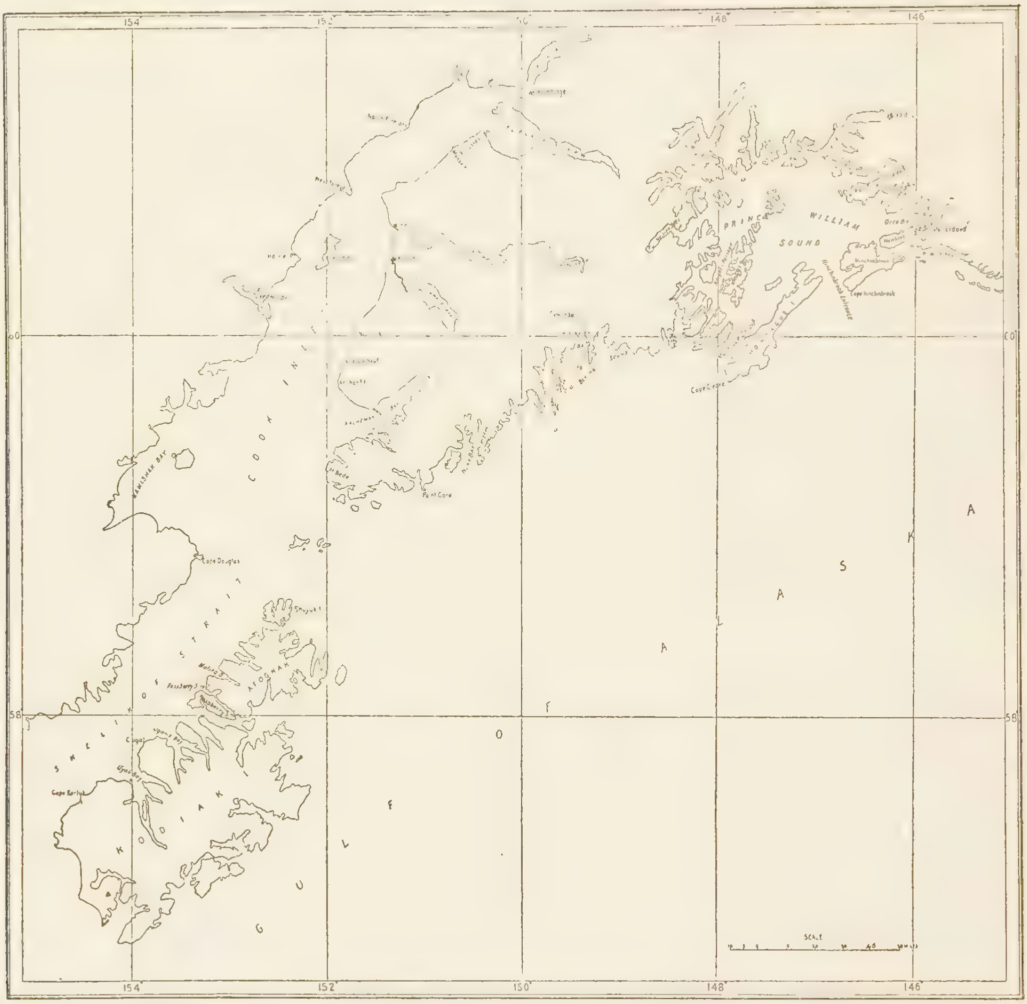

154
152
150
148
146
60
58
PRINCE WILLIAM SOUND
Orca
Hinchinbrook
Cape Hinchinbrook
Hinchinbrook Entrance
Cape Cleare
MONTAGUE I
COOK INLET
KAMISHAK BAY
Pt Bede
Point Gore
Cape Douglas
Shuyak I
AFOGNAK
SHELIKOF STRAIT
Uganik Bay
Uyak Bay
Cape Karluk
KODIAK
GULF OF ALASKA
SCALE
40

FIGURE 1.—Portion of the Gulf of Alaska showing Cook Inlet and Prince William Sound districts

Bidarka Point. North entrance of Port Fidalgo.
Bligh Island. Southeast of Valdez Arm.
Bluff Point. Montague Island. Exact location doubtful.
Cape Cleare. Southwest end of Montague Island.
Dangerous Passage. Between north shore of Chenega Island and the mainland.
Drier Bay. West shore of Knight Island, 3 miles north of Squire Island.
Eaglek Bay. Northwest shore, about 3 miles west of Unakwik Inlet.
Glacier Bay. Northwest shore of Montague Island, about 8 miles northeast of Hanning Bay.
Granite Bay Point. About 2 miles south of Point Nowell.
Hanning Bay. Montague Strait, about 14 miles northeast of Cape Cleare.
Hawkins Cutoff. Between Hawkins Island and Hinchinbrook Island.

Herring Bay. Northwest shore of Knight Island, about 15 miles north of Squire Island.
Hogan Bay. East shore of Knight Island, 2 miles north of Point Helen.
Humpback Creek. Orca Inlet, about 6 miles northeast of Cordova.
Jack Bay. East shore of Valdez Arm, about 12 miles northeast of Point Freemantle.
Jackpot Bay. Dangerous Passage, about 11 miles southwest of Point Nowell.
Johnson Cove. Location unknown. Probably Jackson Cove, Glacier Island.
Johnstone Point. Northwest point of Hinchinbrook Island.
Knowles Head. On mainland about 5 miles south of Port Fidalgo.
Latouche Passage. Between Elrington Island and Latouche Island.
Makaka Point. Southwest end of Hawkins Island.
Marsha Bay. East shore of Knight Island, 12 miles north of Point Helen.
McLeod Harbor. Montague Strait, 7 miles northeast of Cape Cleare.
Pigot Bay. Southwest shore of Port Wells.
Point Freemantle. Western entrance of Valdez Arm.
Point Pellew. Eastern entrance of Eaglek Bay.
Porcupine Point. South entrance of Port Fidalgo.
Port Chalmers. Montague Island, about 10 miles south of Montague Point.
Red Head. Western entrance of Port Gravina.
Rocky Bay. Montague Island, 1 mile south of Montague Point.
Rocky Point. Montague Island, 1 mile northeast of Hanning Bay.
Sandy Point. Montague Island, 6 miles northeast of Hanning Bay.
Sawmill Bay. West shore of Valdez Arm, 10 miles northeast of Point Freemantle.
Seven Sisters. Hinchinbrook Island, 1½ miles south of Johnstone Point.
Sheep Bay. Northeast shore of Orca Bay, 3 miles east of Gravina Point.
Shelter Bay. Hinchinbrook Island, 3 miles south of Johnstone Point.
Simpson Bay. Northeast shore of Orca Bay, 11 miles east of Gravina Point.
Siwash Bay. West shore of Unakwik Inlet, about 8 miles north of entrance.
Squire Island. Near southwest shore of Knight Island.
Valdez Bay. Same as Port Valdez.
Wells Bay. North shore of Prince William Sound, 1½ miles east of Unakwik Inlet.
Whale Bay. Southwest shore of Prince William Sound, 7 miles west of Squire Island.
Windy Bay. Orca Bay, 11 miles northeast of Makaka Point.
Zaikof Bay. Montague Island, 5 miles south of Montague Point.

COOK INLET

Anchor Point. North entrance of Kachemak Bay.
Bluff Point. Kachemak Bay, about 11 miles southeast of Anchor Point.
Boulder Point. East shore of Cook Inlet, 6 miles northeast of East Foreland.
Cape Ninilchik. East shore, about 19 miles north of Anchor Point.
Cape Starichkof. East shore, about 8 miles north of Anchor Point.
Chisik Island. West shore, at entrance to Tuxedin Harbor.
Cottonwood Point. District north of Three Mile Creek.
Dangerous Cape. North entrance of Port Graham.
Deep Creek. Between Cape Ninilchik and Ninilchik Village.
Dogfish Bay. Koyuktolik Bay, 5 miles south of Point Bede.
English Bay. About 3 miles northeast of Point Bede.
False Cape. Part of Dangerous Cape.
Flat Island. One mile north of Point Bede.
Humpy Point. Cape Kasilof, 3 miles south of Kasilof.
Kalifonski. About 4 miles north of Kasilof.
Kamishak Bay. Southwest coast of Cook Inlet.
Kenai. East shore of Cook Inlet at the mouth of the Kenai River.
K. R. P. Co. trap No. 3. East shore, 9½ miles north of Ninilchik.
Lila Bay. Unknown.
Mallard Bay. In Kachemak Bay; exact location doubtful.
McDonald Spit. South shore of Kachemak Bay, approximately 5 miles east of Seldovia Bay.
Moose Point. East shore of Cook Inlet, 30 miles northeast of East Foreland.
Nikishka Bay. Three miles northeast of East Foreland.

Ninilchik. East shore, approximately 21 miles northeast of Anchor Point.
Nubble Point. Kachemak Bay, 4 miles east of Seldovia Bay.
Point Harriet. West shore, 7 miles west of Kalgin Island.
Point McManus. About 32 miles northeast of East Foreland.
Point Naskowhak. Western entrance of Seldovia Bay.
Port Chatham. East shore, about 9 miles south of Point Bede.
Port Graham. About 4 miles northeast of Point Bede.
Sadie Cove. South shore of Kachemak Bay about 8 miles east of Seldovia Bay.
Salamato Beach. East shore, about 7 miles south of East Foreland.
Seldovia Bay. South shore of Kachemak Bay, near the entrance.
Sunset Packing Co. trap No. 1. East shore, 18 miles northeast of East Foreland.
Sunset Packing Co. trap No. 3. East shore, 21 miles northeast of East Foreland.
The Sisters. East shore, 8 miles south of Kasilof.
Three Mile Creek. West shore, latitude 61° 9′.
Tutka Bay. South shore of Kachemak Bay, about 7 miles east of Seldovia Bay.
Tyonek. West shore at North Foreland.
Waterfall. About 10 miles south of Cape Kasilof.
Windy Bay. East shore, 17 miles west of Point Gore.

KODIAK ISLAND

Cape Ugat. Between Uganik Bay and Uyak Bay.
Malina Strait. Same as Raspberry Strait, separating Raspberry Island and Afognak Island.

In the course of the 1929 operations, approximately 4,150 tagged fish were released.

The record of the tags attached is given in Table 1.

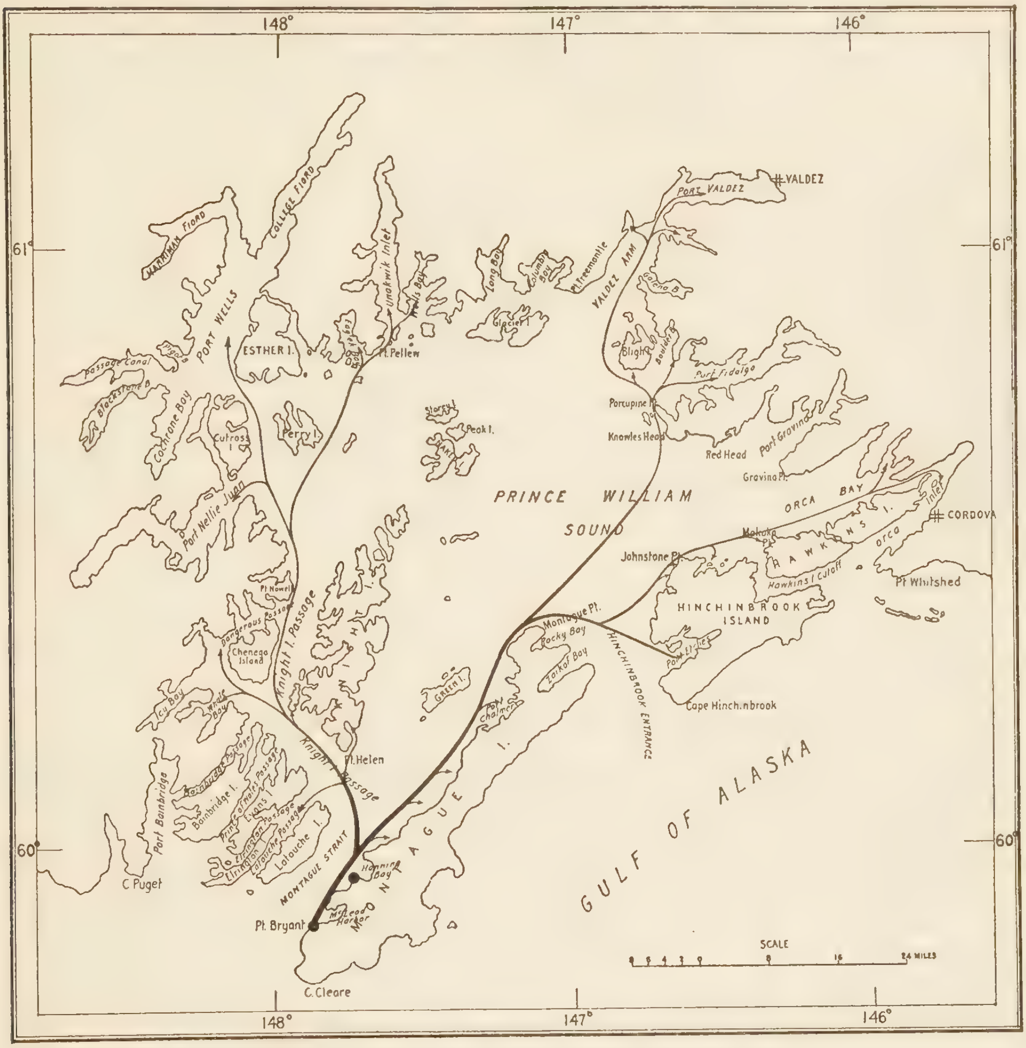
TABLE 1.—*Tags attached in central Alaska, 1929*

Experiment No.	Date	Serial Nos.	Species of fish tagged					Locality
			Red	Pink	Chum	Coho	King	
1	June 14	4701-4850 4901-5000	127	43	26		1	Flat Island.
2	June 26	4851-4950 5001-5300	138	210	51			Nubble Point.
3	June 27	5301-5500 5551-5575	45	99	80		1	Flat Island.
4	July 4	7001-7300	9	281	3	1	6	Point Bryant.
5	July 5	7301-7600		299	1			Montague Point.
6	July 5	7601-8000		400				Port Etches.
7	July 12	8001-8200		200				Squire Island.
8	July 13	8201-8400		200				Hanning Bay.
9	July 13	8401-8600		200				Montague Point.
10	July 15	8601-8750	1	121	23	5		Johnstone Point.
11	July 18	5601-5800	13	187				Nubble Point.
12	July 21	5801-6050	245			3		Nikishka Bay.
13	July 22	6050-6400	202	121		27		Cape Starichkof.
14	July 23	5501-5550 5576-5600 6401-6600	18	171	67	18		Flat Island.
15	July 30	8751-8900 6601-6700	5	221	20	4		Johnstone Point.
16	July 31	6701-6950		250				Montague Point.

PRINCE WILLIAM SOUND

RETURNS FROM EXPERIMENTS IN MONTAGUE STRAIT

Pink salmon.—Experiments were conducted at Point Bryant and at Hanning Bay in which 481 pink salmon were tagged and liberated. Of this number, 171 (35.6 per cent) were recaptured in many localities in Prince William Sound. The data are presented in Table 2. Two main routes of migration are indicated and are shown graphically in Figure 2. The movement northeast along Montague Island to Hinchinbrook Entrance and from there to many of the bays and inlets tributary to the east shore of Prince William Sound appears to be of somewhat greater importance than that through Knight Island Passage to the spawning grounds along the western shore. Sixty-six (38.6 per cent) of the recaptured salmon were taken along the shore of Montague Island northeast of the locality of tagging. One tagged fish was reported to have been taken in Cook Inlet, but more specific information was not available, and the accuracy of the report is questionable.


148°
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VALDEZ
PORT VALDEZ
VALDEZ ARM
HARRIMAN FIORD
COLLEGE FIORD
PORT WELLS
Unakwik Inlet
Long Bay
Columbia Bay
Pt. Freemantle
Galena B.
Glacier I.
ESTHER I.
Pt. Pellew
Bligh I.
Boulder B.
Port Fidalgo
Passage Canal
Blackstone B.
Cochrane Bay
Culross I.
Perry I.
Storey I.
Peak I.
Naked I.
Porcupine Pt.
Knowles Head
Red Head
Port Gravina
Gravina Pt.
PRINCE WILLIAM SOUND
ORCA BAY
Inlet
CORDOVA
Port Nellie Juan
Mokaka Pt.
HAWKINS I.
Orca
Johnstone Pt.
Hawkins I. Cutoff
Pt. Whitshed
Pt. Nowell
Dangerous Passage
Chenega Island
Knight I. Passage
KNIGHT I.
HINCHINBROOK ISLAND
Montague Pt.
Rocky Bay
Zaikof Bay
HINCHINBROOK ENTRANCE
Port Etches
Cape Hinchinbrook
Green I.
Icy Bay
Whale Bay
Port Chalmers
Pt. Helen
Knight I. Passage
Port Bainbridge
Bainbridge I.
Bainbridge Passage
Prince of Wales Passage
Evans I.
Elrington Passage
Latouche Passage
Elrington I.
Latouche I.
MONTAGUE STRAIT
MONTAGUE I.
GULF OF ALASKA
C Puget
Hanning Bay
Pt. Bryant
MacLeod Harbor
C. Cleare
SCALE
24 MILES

FIGURE 2.—Distribution of pink salmon tagged in Montague Strait

There were no important differences in the direction of migration or distribution of the fish tagged during the early part of the season and those tagged at its height. The fish liberated in the first experiment were, however, recaptured after a greater period of freedom, indicating a somewhat slower rate of travel.

TABLE 2.—*Returns from pink salmon tagged in Montague Strait*

Locality of recapture	Locality and date of tagging				Total number recaptured
	Point Bryant, July 4		Hanning Bay, July 13		
	Number	Time in days	Number	Time in days	
Montague Island:					
No details	13	1-25	13	3-19	26
McLeod Harbor			3	15-34	3
Hanning Bay	3	6-8	4	8	7
Sandy Point			9	4-9	9
Rocky Point	5	1-28	4	9	9
Glacier Bay	4	13-24	5	8-15	9
Port Chalmers	3	12			3
Latouche Passage	2	7			2
Whale Bay			2	3-14	2
Knight Island:					
Hogan Bay	1	23			1
Drier Bay	1	15			1
Squire Island			13	6-14	13
Dangerous Passage:					
No details	2	19			2
Chenega Island	1	13			1
Granite Bay Point	4	15-29	2	9-13	6
Port Nellie Juan	1	27			1
Port Wells			3	18-20	3
Eaglek Bay			3	13-19	3
Point Pellew	2	19-22			2
Siwash Bay			1	13	1
Wells Bay	4	19			4
Port Etches	5	7-18	3	7-12	8
Seven Sisters	3	7-19	1	6	4
Johnstone Point			1	20	1
Anderson Bay	3	5-14	1	18	4
Makaka Point	2	6-7			2
Orca Inlet	1	4			1
Simpson Bay	2	4-15			2
Knowles Head	1	5	7	4-13	8
Porcupine Point			1	14	1
Port Fidalgo	1	6			1
Bidarka Point	1	4	1	11	2
Bligh Island, south end	4	5-21	1	6	5
Port Valdez:					
Jack Bay	2	20-23	2	13-21	4
Sawmill Bay	1	23	2	14-21	3
Valdez Bay	1	19	1	9	2
Johnson's Cove			1	20	1
Prince William Sound, east shore	[1] 10		[1] 3		13
Cook Inlet	1	21			1
Total	84		87		171
Per cent returned	29.9		43.5		35.6

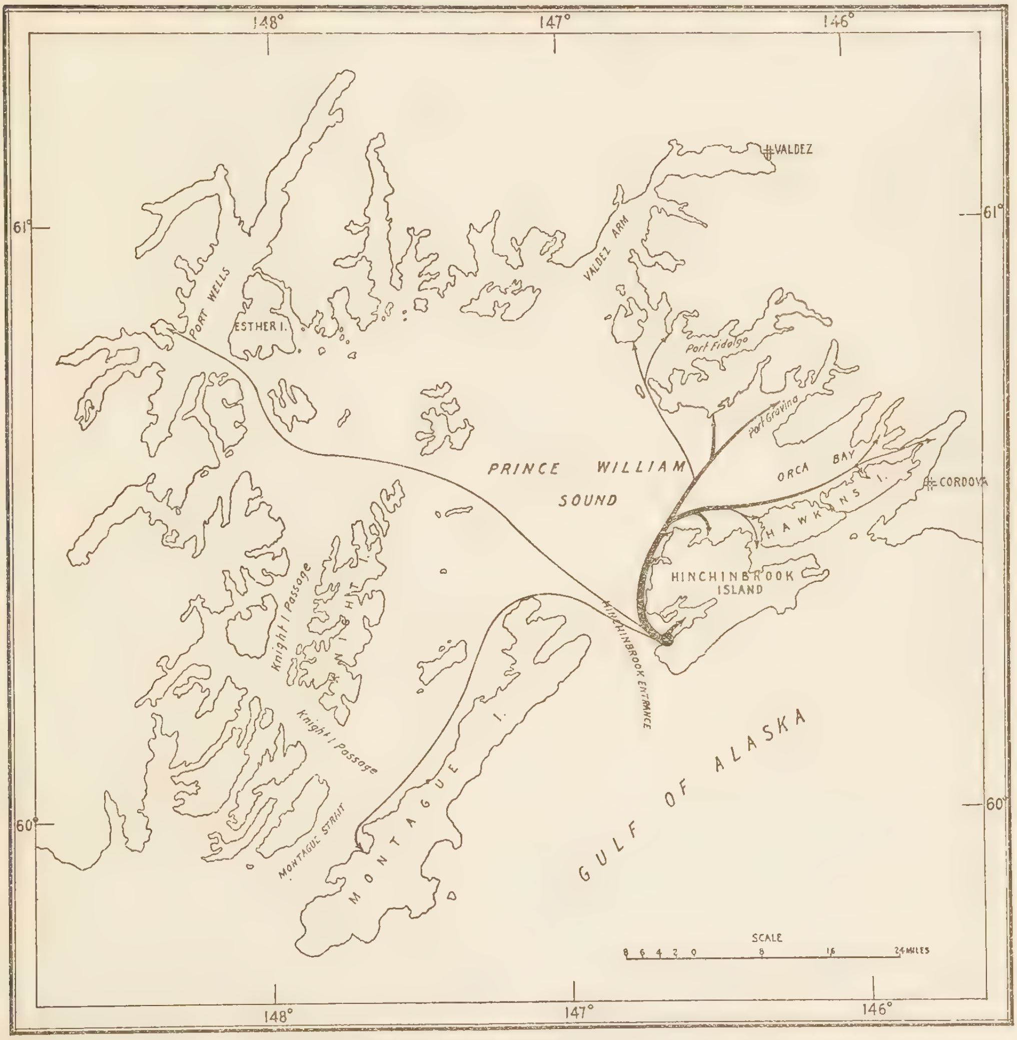
[1] Date of capture not reported.

Red salmon.—Nine red salmon were tagged here and one was recaptured in Simpson Bay 29 days later.

RETURNS FROM EXPERIMENTS AT MONTAGUE POINT

Pink salmon.—The data secured from the tagging of pink salmon at Montague Point are given in Table 3 and are graphically shown in Figure 3. Three experiments were conducted here in which 749 pinks and 1 chum salmon were tagged. The latter was not recaptured. Of the pink salmon, 271 (36.1 per cent) were recaptured in all parts of Prince William Sound. The dispersion of the fish tagged on July 5 and on July 13 was almost identical. However, those tagged on July 31 were, with few exceptions, taken within a comparatively short time in the immediate vicinity of Montague Point. This may have been due to the fact that commercial fishery operations ceased within a week after the tagging, but the taking of 28.3 per cent of the recaptures in Rocky Bay by purse seines would indicate that the fish were bound for near-by spawning grounds.

The fish tagged here are doubtlessly derived, in part, from the fish entering Prince William Sound through Montague Strait. Others may have entered through Hinchinbrook Entrance but, as seen from the experiment at Port Etches, they are not associated with the fish caught along the east shore of Hinchinbrook Entrance. It is probable that the salmon liberated at Montague Point had entered the sound through both entrances and were a mixed lot. This would account for the wide scattering of fish from this point, for had all of them been derived from fish entering through Montague Strait only an extensive northerly and easterly migration would have been expected.


148°
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VALDEZ
VALDEZ ARM
PORT WELLS
ESTHER I.
Port Fidalgo
Port Gravina
PRINCE WILLIAM SOUND
ORCA BAY
HAWKINS I.
CORDOVA
HINCHINBROOK ISLAND
HINCHINBROOK ENTRANCE
Knight I. Passage
KNIGHT I.
Knight I. Passage
MONTAGUE STRAIT
MONTAGUE I.
GULF OF ALASKA
SCALE
8 6 4 2 0 8 16 24 MILES

FIGURE 3.—Distribution of pink salmon tagged at Montague Point

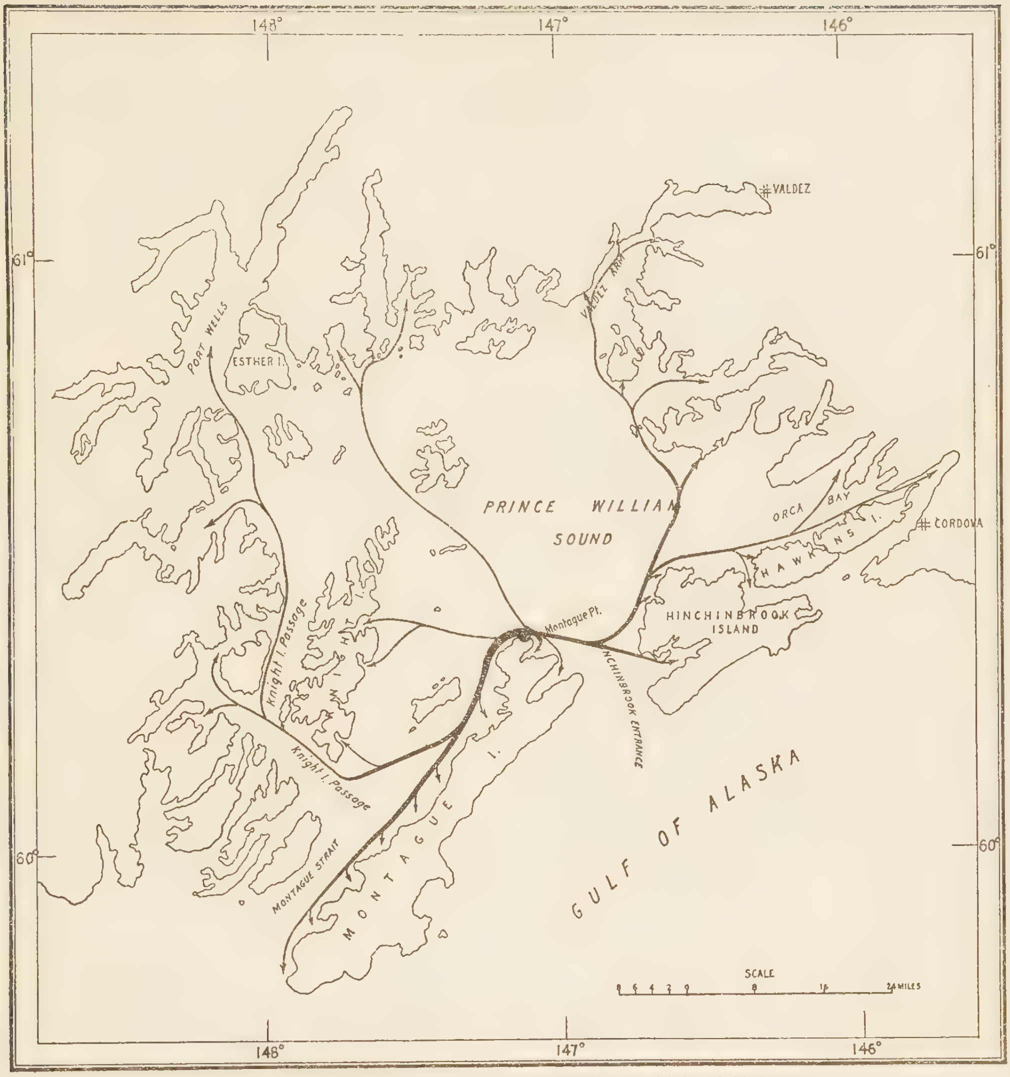
TABLE 3.—*Returns from pink salmon tagged in Montague Point*

Locality of recapture	Date of tagging						Total number recaptured
	July 5		July 13		July 31		
	Number	Time in days	Number	Time in days	Number	Time in days	
Montague Island:							
No details	40	1-28	28	3-19	[1] 35	1-2	103
Zaikof Bay	1	24	1	16			2
Rocky Bay	1	21	1	13	[2] 19		21
Port Chalmers	1	10	1	5			2
Glacier Bay	4	16-23	1	12			5
Rocky Point	1	10	1	6			2
Bluff Point	1	22	1	4			2
Sandy Point	1	13	1	5			2
Hanning Bay	3	5	1	8			4
McLeod Harbor			1	15			1
Cape Cleare	1	19	1	11			2
Port Etches	5	4-20	[3] 8	1-11	1	2	14
Shelter Bay	1	11	1	4			2
Seven Sisters	1	11	5	4-12			6
Anderson Bay	1	7	2	9-13			3
Makaka Point	1	6	2	4			3
Hawkins Cutoff			[3] 1				1
Orca Inlet	2	14-26					2
Simpson Bay	1	6					1
Red Head	3	28	3	5-6			6
Knowles Head			1	11			1
Porcupine Point			1	6			1
Port Fidalgo	3	5-17					3
Bidarka Point	1	3					1
Bligh Island	2	6	1	12			3
Valdez Arm:							
Point Freemantle	1	28			[3] 1		2
Jack Bay	1	15					1
Sawmill Bay			1	21			1
Squire Island	3	6	10	3-10			13
Knight Island:							
Bay of Isles			1	6			1
Marsha Bay	1	16					1
Hogan Bay	1	22					1
Drier Bay	6	18-25	3	17			9
Herring Bay			1	6			1
Whale Bay	3	16-22	2	9			5
Dangerous Passage	3	27					3
Granite Bay Point	5	7-12	4	9-11			9
Port Nellie Juan					[3] 1		1
Port Wells			1	20	1	2	2
Eaglek Bay	1	21	1	13			2
Point Pellew	4	20-21	2	17	[3] 2	2	8
Wells Bay					[3] 1		1
Prince William Sound, east shore	[4] 8		[4] 3		[4] 6		17
Total	112		92		67		271
Per cent return	37.5		46.0		26.8		36.1

[1] Ten reported taken before date of tagging.
[2] All reported taken before date of tagging.
[3] One reported taken before date of tagging.
[4] Date of capture not reported.

RETURNS FROM EXPERIMENT IN HINCHINBROOK ENTRANCE

Pink salmon.—Four hundred pink salmon were tagged in Hinchinbrook Entrance at Port Etches. Of these fish 194 (48.5 per cent) were recaptured, with two exceptions, along the east shore of Prince William Sound. Of the recoveries, 53.6 per cent were made in Port Etches after a time of from 1 to 28 days and after an average length of time of 6.3 days. The data are presented in Table 4 and are graphically shown in Figure 4.


148°
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VALDEZ
VALDEZ ARM
PORT WELLS
ESTHER I.
PRINCE WILLIAM SOUND
ORCA BAY
CORDOVA
HAWKINS I.
HINCHINBROOK ISLAND
Montague Pt.
HINCHINBROOK ENTRANCE
Knight I. Passage
KNIGHT I.
MONTAGUE STRAIT
MONTAGUE I.
GULF OF ALASKA
SCALE
24 MILES

FIGURE 4.—Distribution of pink salmon tagged in Hinchinbrook Entrance

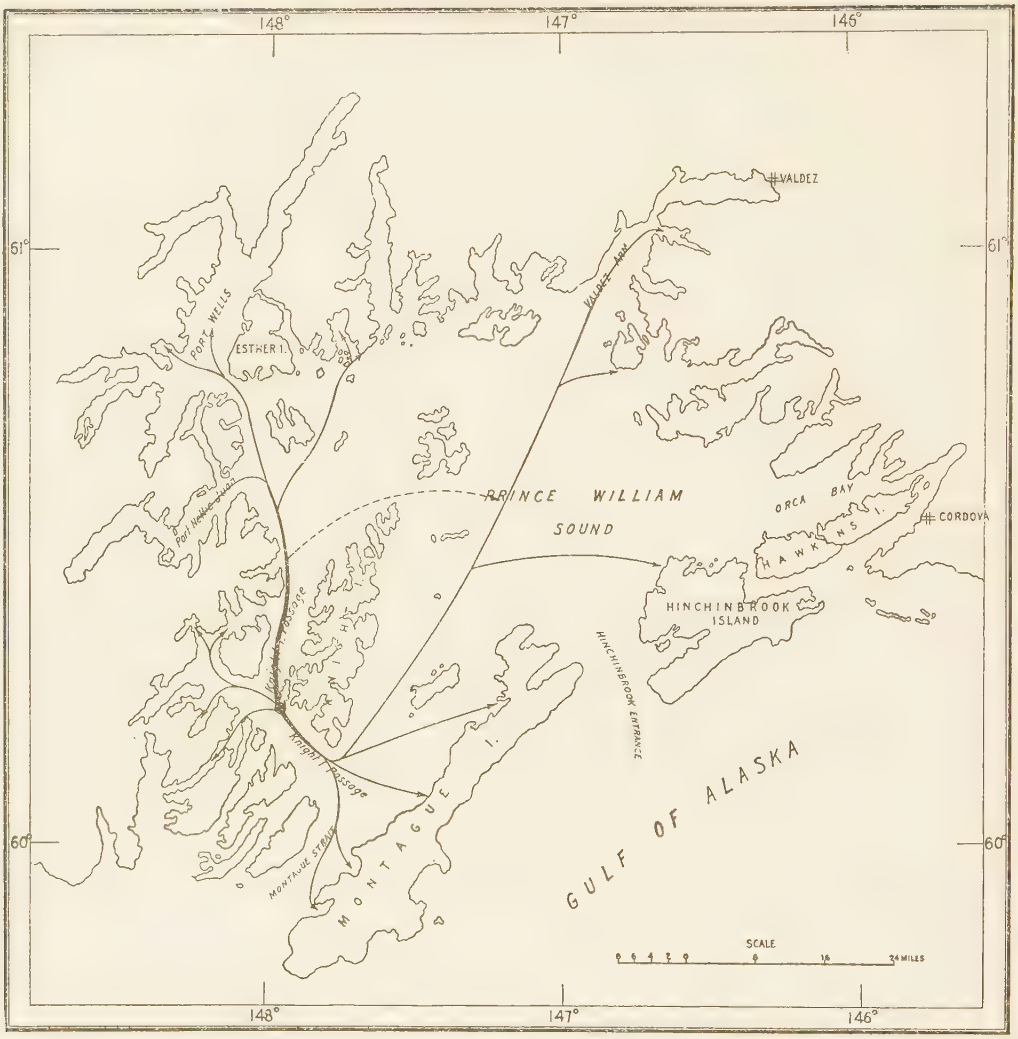
TABLE 4.—*Returns from pink salmon tagged at Port Etches, Hinchinbrook Entrance, July 5*

Locality of recapture	Number	Time in days	Locality of recapture	Number	Time in days
Port Etches	104	1–28	Port Gravina	8	5–14
Shelter Bay	9	3–13	Red Head	9	8
Seven Sisters	6	6–20	Knowles Head	1	12
Anderson Bay	21	1–28	Bidarka Point	1	5
Hawkins Cutoff	2	13–19	Bligh Island	1	20
Hawkins Island:			Port Wells: Pigot Bay	1	3
No details	2	6	Montague Island: Hanning Bay	1	4
Makaka Point	9	5–12	East shore Prince William Sound	[1] 16	-------
Windy Bay	1	17			
Orca Inlet: Humpback Creek	1	17	Total	194	-------
Simpson Bay	1	6	Per cent returned	48. 5	-------

[1] Date of capture not reported.

RETURNS FROM EXPERIMENT IN KNIGHT ISLAND PASSAGE

Pink salmon.—Two hundred pink salmon were tagged at the south end of Squire Island and 72 (35.5 per cent) were recaptured. The migration from this locality is principally north through Knight Island Passage to the spawning streams along the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VALDEZ ARM
PORT WELLS
ESTHER I.
Port Nellie Juan
PRINCE WILLIAM SOUND
ORCA BAY
HAWKINS I.
CORDOVA
HINCHINBROOK ISLAND
HINCHINBROOK ENTRANCE
Knight I. Passage
Knight I. Passage
MONTAGUE STRAIT
MONTAGUE I.
GULF OF ALASKA
SCALE
24 MILES

FIGURE 5.—Distribution of pink salmon tagged in Knight Island Passage

west shore of the sound. Four fish were recaptured on Montague Island, and four were taken in three widely separated localities on the east shore. The data are given in Table 5 and Figure 5.

TABLE 5.—*Returns from pink salmon tagged at Squire Island, Knight Island Passage, July 12*

Locality of recapture	Number	Time in days	Locality of recapture	Number	Time in days
Squire Island	[1] 23	1–12	Knight Island:		
Bainbridge Passage	1	7	Marsha Bay	3	9
Montague Island:			Hogan Bay	2	15
No details	4	11–20	Drier Bay	2	8–14
McLeod Harbor	1	16	Port Nellie Juan	1	10
Hanning Bay	1	9	Port Wells:		
Glacier Bay	1	13	No details	2	1–6
Port Chalmers	1	6	Pigot Bay	2	13
Seven Sisters	1	6	Eaglek Bay	2	10–18
Dangerous Passage:			Point Pellew	2	18
No details	3	1	Valdez Arm: Jack Bay	2	11–19
Jackpot Bay	1	13	Bligh Island	1	7
Granite Bay Point	11	1–12	Prince William Sound, east shore	[2] 1	-------
Whale Bay	4	15–16			
			Total	72	-------
			Per cent returned	35.5	-------

[1] Two reported taken before date of tagging.

[2] Date of capture not reported.

It has often been suggested that the fish taken at Squire Island enter Prince William Sound chiefly through Bainbridge and Prince of Wales Passages, but the number of fish tagged in Montague Strait and recaptured at Squire Island would indicate a very definite westward migration from Montague Strait through Knight Island Passage. It seems probable, therefore, that the majority of the fish that pass through Knight Island Passage enter from Montague Strait and not through the other smaller channels.

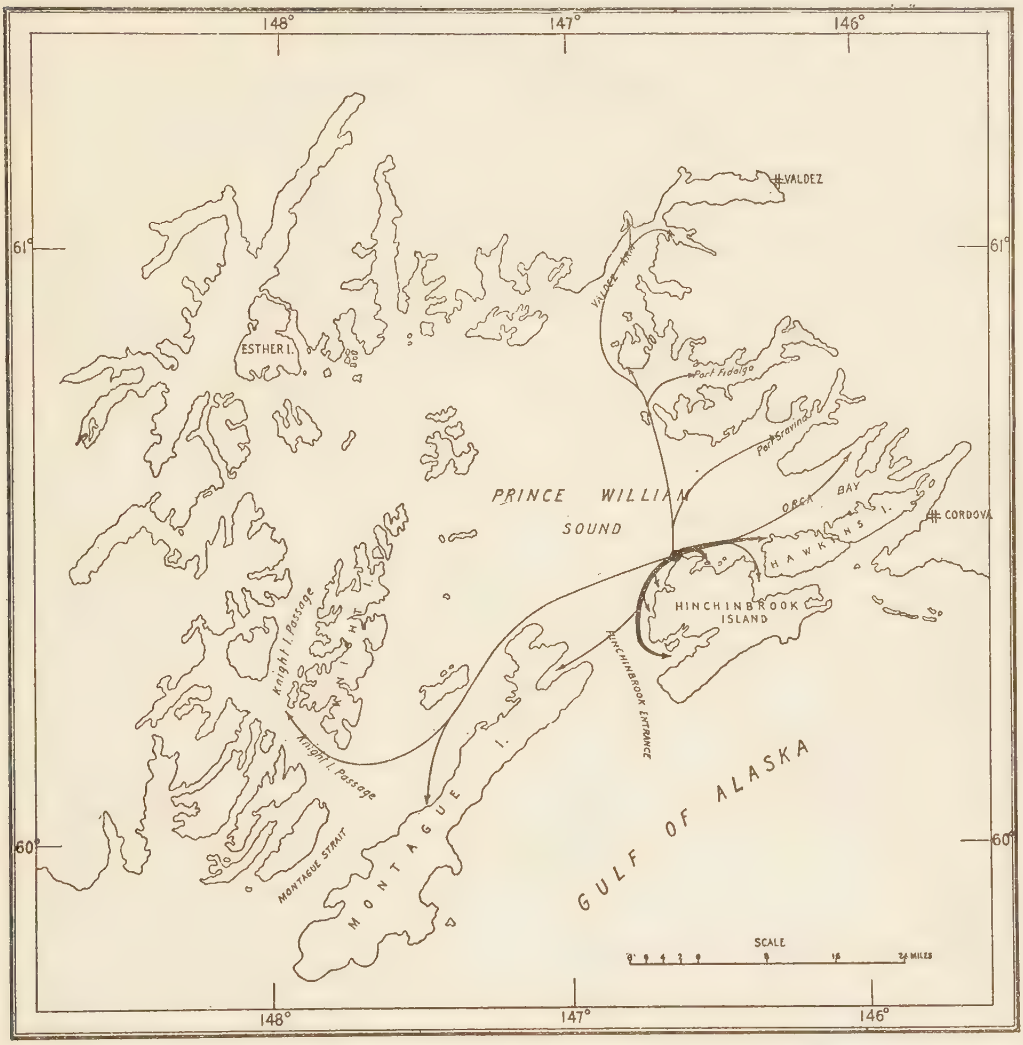
148°
147°
146°
61°
60°
VALDEZ
Valdez Arm
ESTHER I.
Port Fidalgo
Port Gravina
PRINCE WILLIAM SOUND
ORCA BAY
HAWKINS I.
CORDOVA
HINCHINBROOK ISLAND
Hinchinbrook Entrance
Knight I. Passage
KNIGHT I.
Knight I. Passage
MONTAGUE STRAIT
MONTAGUE I.
GULF OF ALASKA
SCALE
24 MILES

FIGURE 6.—Distribution of pink salmon tagged at Johnstone Point

RETURNS FROM EXPERIMENTS AT JOHNSTONE POINT

Pink salmon.—Tagging experiments were conducted at Johnstone Point on July 15 and again on July 30. In these experiments, 342 pink salmon were tagged and 117 (34.2 per cent) were recaptured. The recaptures, with few exceptions, were made along the east shore of Prince William Sound. The returns are shown in Table 6 and Figure 6.

Red salmon.—Six red salmon were tagged here and one was recaptured three days later at Knowles Head.

Chum salmon.—Forty-three chums were tagged and eight were recaptured later. All of the recaptured chum salmon were tagged during the experiment of July 15. The data are given in Table 6 showing that the chum salmon taken here were of local origin, spawning in the streams emptying into the bays in the vicinity of Johnstone Point.

Coho salmon.—Nine cohos were tagged and three were later recaptured. Two were taken at Rocky Point on Montague Island after 7 and 15 days, and one was captured in Port Etches after 3 days.

TABLE 6.—*Returns from salmon tagged at Johnstone Point*

PINK SALMON

Locality of recapture	Date of tagging				Total number recaptured
	July 15		July 30		
	Number	Time in days	Number	Time in days	
Anderson Bay	[1] 17	1–28	[1] 13	1–4	30
Hawkins Cutoff			[2] 1		1
Makaka Point	1	4	5	3–23	6
Sheep Bay			1	1	1
Port Gravina	1	4			1
Knowles Head	3	3–6			3
Port Fidalgo			1	3	1
Bligh Island	1	10	2	3	3
Valdez Arm:					
Jack Bay			2	4	2
Sawmill Bay			1	4	1
Seven Sisters	[2] 17	1–17	[1] 9	1–5	26
Shelter Bay	2	2	2	1–4	4
Port Etches	11	1–7	6	1–3	17
Montague Island:					
No details			3	2–4	3
Zaikof Bay			1	1	1
Glacier Bay	1	10			1
Squire Island	1	1			1
Prince William Sound, east shore	[3] 4		[3] 11		15
Total	59		58		117
Per cent returned	48.8		26.2		34.2
CHUM SALMON					
Seven Sisters	3	1–10			3
Port Etches	1	3			1
Anderson Bay	2	3–5			2
Hawkins Cutoff	1	3			1
Prince William Sound, east shore	[4] 1				1
Total	8		0		8
Per cent returned	34.8		0		18.6

[1] Three reported taken before date of tagging.
[2] One reported taken before date of tagging.
[3] Date of capture not reported.

COOK INLET

RETURNS FROM EXPERIMENTS AT FLAT ISLAND

Three experiments were conducted at Flat Island, on June 14, June 27, and on July 23, in which 696 salmon were tagged. Of this number, 190 were reds; 313 were pinks; 173 were chums; 18 were cohos; and 2 were kings, neither of which was recaptured.

Red salmon.—The returns from the red salmon tagged at Flat Island are shown in Table 7 and indicate a northerly migration chiefly to the streams south of Anchor Point. The returns from the experiment of June 14 show a very definite migration into English Bay while in the later experiments fewer fish were taken in that vicinity.

This is in accord with the record of the counting weir in the river emptying into English Bay, which shows the run to be an early one and accounts for the number of fish taken there from the first experiment. Three fish tagged June 14 were taken in the waters of the Kodiak Island group 20 days after they were tagged, and 2 were taken in Prince William Sound after 12 and 21 days of freedom.

TABLE 7.—*Returns from salmon tagged at Flat Island*

RED SALMON

Locality of recapture	Date of tagging						Total number recaptured
	June 14		June 27		July 23		
	Number	Time in days	Number	Time in days	Number	Time in days	
Cook Inlet:							
No details	2	14–18					2
Flat Island	9	5–8	3	1	2	4–7	14
English Bay	9	2–16	2	3	1	1	12
Port Graham	1	5	2	24			3
Kachemak Bay—							
No details	1	18					1
Nubble Point	3	9–16	2	1–5			5
Mallard Bay					[1] 2	8	2
Bluff Point					1	4	1
Salamato Beach	1	6					1
Prince William Sound:							
McLeod Harbor					1	12	1
Port Etches			1	21			1
Kodiak Island:							
Cape Ugat	2	20					2
Between Malina Strait and Cape Ugat	1	20					1
Total	29		10		7		46
Per cent returned	22.8		22.2		38.9		24.2

PINK SALMON

Locality of recapture	June 14 Number	June 14 Time in days	June 27 Number	June 27 Time in days	July 23 Number	July 23 Time in days	Total number recaptured
Cook Inlet:							
No details	2	18–23	3	3–23	3	2–5	8
Windy Bay					1	3	1
Port Chatham			1	18			1
Flat Island			1	11	8	4–13	9
English Bay			1	28	23	1–28	24
Port Graham	2	17	4	4–11	[2] 35	2–30	41
Dangerous Cape					6	10	6
False Cape	1	21			4	1–2	5
Point Naskowhak	7	12–16	1	1			8
Kachemak Bay—							
No details	1	25	1	5	4	3–12	6
Seldovia Bay	7	18–46	7	6–28			14
Nubble Point	3	13–17	12	1–38	3	4	18
Tutka Bay					1	8	1
Mallard Bay					[3] 1		1
Sadie Cove			1	33			1
Bluff Point			2	9	10	1	12
Salamato Beach					1	2	1
Boulder Point					1	8	1
Kamishak Bay					1	5	1
Prince William Sound:							
Montague Island					1	8	1
Port Wells			1	35			1
Valdez Arm: Sawmill Bay					1	11	1
Total	23		35		104		162
Per cent returned	53.5		35.4		60.8		51.8

CHUM SALMON

Locality of recapture	June 14 Number	June 14 Time in days	June 27 Number	June 27 Time in days	July 23 Number	July 23 Time in days	Total number recaptured
Cook Inlet:							
No details			1	17			1
Windy Bay					1	3	1
Dogfish Bay (Koyuktolik Bay)					3	2	3
Flat Island			5	1–11	5	4–7	10
Port Graham	7	4–16	4	4–15			11
False Cape					3	2–4	3
Point Naskowhak	2	7–15	2	1			4
Kachemak Bay—							
No details	1	47	2	5–38			3
Seldovia Bay					1	1	1
Nubble Point			2	5–6	2	1–12	4
Tutka Bay					1	8	1
Sadie Cove					1	8	1
Total	10		16		17		43
Per cent returned	38.5		20.0		35.4		24.9

[1] One reported taken before date of tagging. [2] Three reported taken before date of tagging. [3] Reported before date of tagging.

Pink salmon.—Of the 313 pink salmon tagged here, 162 (51.8 per cent) were recaptured. The data are presented in Table 7. There was a distinct northerly movement up Cook Inlet into Port Graham, and into the many bays in Kachemak Bay, where 32.7 per cent of the recaptures were made. Only 2 fish were reported taken north of Anchor Point and they were both tagged in the experiment of July 23. Two were taken south of Flat Island in Port Chatham and Windy Bay, 1 in Kamishak Bay on the west shore of Cook Inlet, and 3 were taken in different parts of Prince William Sound after periods of from 8 to 35 days.

Chum salmon.—As in the case of the pink salmon, the chums tagged at Flat Island were distributed to the bays and inlets along the east shore of Cook Inlet south of Anchor Point. Of the 173 chums tagged, 43 (24.9 per cent) were recaptured. The data are given in Table 7.

Coho salmon.—Eighteen cohos were tagged in the final experiment at Flat Island and 3 (16.7 per cent) were recaptured; 1 at Flat Island after 4 days, 1 in Port Graham after 2 days, and 1 in Mallard Bay after 8 days.

RETURNS FROM EXPERIMENTS AT NUBBLE POINT

Experiments were conducted here on June 26 and on July 18. Out of a total of 599 fish tagged, 151 were red salmon, 397 were pinks, and 51 were chums.

Red salmon.—The data relative to the capture of red salmon tagged at this locality are given in Table 8. From this table it may be seen that the fish were largely bound for spawning streams along the east shore of Cook Inlet. Of the recoveries, 21.6 per cent were made north of Anchor Point, indicating that a part of these fish were bound for the larger spawning streams of the upper inlet.

It is interesting to note that all fish other than those taken along the east shore of Cook Inlet were tagged early in the season. One was taken at Chisik Island on the west shore, 1 at Kalgin Island, 3 in the vicinity of Kodiak Island after from 4 to 8 days, and 2 in Prince William Sound after 13 and 17 days.

Pink salmon.—Of the 397 pink salmon tagged, 250 (63 per cent) were recaptured and the data are presented in Table 8. As in the case of the Flat Island experiments, the recoveries of tagged pink salmon were confined almost entirely to the bays indenting the east shore of Cook Inlet south of Anchor Point. One hundred and sixty-five (66 per cent) of the recaptures were made in Kachemak Bay, the streams of which provide the largest known pink salmon spawning grounds in Cook Inlet. One fish was taken at Anchor Point and one was taken north of Anchor Point at Deep Creek.

Chum salmon.—Fifty-one chum salmon were tagged in the experiment of June 26, and 26 (51 per cent) were recaptured. The data are presented in Table 13. The localities where recaptures were made are almost identical with the localities of recaptured chum salmon tagged at Flat Island.

TABLE 8.—*Returns from salmon tagged at Nubble Point*

RED SALMON

Locality of recapture	Date of tagging: June 26 Number	June 26 Time, in days	July 18 Number	July 18 Time, in days	Total number recaptured
Cook Inlet:					
No details	4	4-18	------	-------	4
Flat Island	1	5	------	-------	1
English Bay	1	28	1	21	2
Port Graham	2	16-29	------	-------	2
False Cape	1	9	------	-------	1
Point Naskowhak	3	2	------	-------	3
Kachemak Bay—					
No details	2	9-34	1	12	3
Seldovia Bay	5	4- 9	1	7	6
Nubble Point	8	1- 7	1	2	9
Tutka Bay	2	9-18	------	-------	2
Bluff Point	2	11-12	------	-------	2
Cape Starichkof	1	10	------	-------	1
Cape Ninilchik	2	13	------	-------	2
Ninilchik	1	29	------	-------	1
K. R. P. Co. trap No. 3	1	7	------	-------	1
Kenai	------	-------	1	13	1
Cook Inlet—Continued.					
Salamato Beach	1	10	------	-------	1
Moose Point	1	20	------	-------	1
Sunset Packing Co., trap No. 1	1	14	------	-------	1
Kalgin Island	1	21	------	-------	1
Chisik Island	1	20	------	-------	1
Kodiak Island:					
Cape Ugat	2	8	------	-------	2
Malina Strait	1	4	------	-------	1
Prince William Sound:					
Montague Island—					
Rocky Point	1	17	------	-------	1
Knowles Head	1	13	------	-------	1
Total	46	-------	5	-------	51
Per cent returned	33.3	-------	38.5	-------	33.8

PINK SALMON

Locality of recapture	Date of tagging: June 26 Number	June 26 Time, in days	July 18 Number	July 18 Time, in days	Total number recaptured
Cook Inlet:					
No details	20	4-29	30	1- 9	50
Flat Island	1	6	1	13	2
English Bay	------	-------	2	8-13	2
Port Graham	1	16	3	3-11	4
False Cape	1	27	5	1- 7	6
Point Naskowhak	5	2- 4	------	-------	5
Kachemak Bay—					
No details	8	13-34	11	6-17	19
Seldovia Bay	[1] 18	1-34	7	1- 7	25
Nubble Point	47	1-32	44	1-13	91
McDonald Spit	------	-------	1	6	1
Cook Inlet—Continued.					
Kachemak Bay—Con.					
Tutka Bay	7	9-35	4	2-13	11
Sadie Cove	2	28-30	5	4-12	7
Mallard Bay	3	23-27	7	1-13	10
Bluff Point	1	24	9	2	10
Lila Bay	------	-------	1	14	1
Anchor Point	------	-------	5	1- 6	5
Deep Creek	1	8	------	-------	1
Total	115	-------	135	-------	250
Per cent returned	54.8	-------	72.2	-------	63.0

[1] Five reported taken before date of tagging.

TABLE 9.—*Returns from chum salmon tagged at Nubble Point, June 26*

Locality of recapture	Number	Time in days
Cook Inlet:		
No details	2	2- 4
English Bay	1	29
Port Graham	4	7-29
Point Naskowhak	1	2
Kachemak Bay—		
No details	1	32
Seldovia Bay	5	7- 9
Cook Inlet—Continued.		
Kachemak Bay—Continued.		
Nubble Point	9	2-35
Tutka Bay	2	9-35
Anchor Point	1	13
Total	26	---------
Per cent returned	51.0	---------

RETURNS FROM EXPERIMENT AT CAPE STARICHKOF

Three hundred and fifty salmon were tagged at Cape Starichkof on July 22. Of this number 202 were red salmon, 121 were pinks, and 27 were cohos.

Red Salmon.—The returns from the red salmon tagged at Cape Starichkof, as given in Table 10, indicate that the principal migration is north along the east shore of Cook Inlet to the Kenai and Kasilof Rivers. A migration of lesser importance is southeast into Kachemak Bay. One tagged fish was captured on the west shore of Cook Inlet at Tyonek, and one was reported taken on August 29 at the mouth of the Ugashik River, Bristol Bay.

Pink Salmon.—The returns from pink salmon tagged at Cape Starichkof are shown in Table 11, and indicate the principal migration to be southeast into Kachemak Bay. Only 9 fish, or 11.3 per cent of the recaptures, were taken north of Anchor Point, while 73.8 per cent were made in Kachemak Bay.

Coho Salmon.—Only 4 (15.4 per cent) of the 27 cohos tagged at Cape Starichkof were recaptured; 1 was taken at False Cape, 1 in Seldovia Bay, 1 at Cape Starichkof, and 1 at Salamato Beach. The scattering returns of this species do not indicate any extensive or definite migration.

TABLE 10.—*Returns from salmon tagged at Cape Starichkof, July 22*

RED SALMON

Locality of recapture	Number	Time in days	Locality of recapture	Number	Time in days
Cook Inlet:			Cook Inlet—Continued.		
No details	6	3- 8	Kalifonski	5	4- 7
False Cape	5	3- 5	The Sisters	4	2- 5
Kachemak Bay—			Waterfall	1	4
No details	3	5-11	Kenai	5	4- 9
Seldovia Bay	[1] 2		Salamato Beach	6	3- 8
Nubble Point	2	3- 9	East Foreland	1	4
Sadie Cove	1	4	Nikishka Bay	5	4- 9
Mallard Bay	1	6	Boulder Point	2	8- 9
Bluff Point	11	2-10	Sunset Packing Co. trap No. 3	2	2
Anchor Point	3	2	North Foreland: Tyonek	2	9
Cape Starichkof	2	5	Bristol Bay: Ugashik River	1	36
Ninilchik	2	5-10			
Kalgin Island	2	7- 8	Total	75	
Humpy Point	1	3	Per cent returned	37. 1	

PINK SALMON

Locality of recapture	Number	Time in days	Locality of recapture	Number	Time in days
Cook Inlet:			Cook Inlet—Continued.		
No details	4	2-9	Anchor Point	6	1-2
False Cape	1	3	Cape Starichkof	4	2-5
Kachemak Bay—			Ninilchik	1	5
No details	[2] 17	3-9	Kalifonski	1	5
Seldovia Bay	[1] 2		Salamato Beach	3	3
Nubble Point	4	1-8	Kamishak Bay	1	6
Tutka Bay	[1] 2				
Sadie Cove	5	2-9	Total	80	
Mallard Bay	[2] 8	1-4	Per cent return	66. 1	
Bluff Point	21	2			

[1] Reported taken before date of tagging.

[2] One reported taken before date of tagging.

RETURNS FROM EXPERIMENT AT NIKISHKA BAY

One experiment was conducted here on July 21, at the height of the red salmon run and during the weekly 48-hour closed season, so that the fish had an opportunity to escape recapture for considerable time. Of the 248 fish tagged, 245 were red salmon and 3 were cohos. For some time there has been a question among canners as well as Bureau of Fisheries officials, as to whether the red salmon caught on the east shore of Cook Inlet north of East Foreland are bound for spawning grounds in the Susitina River or other rivers in the upper inlet, or whether they first strike the east shore north of East Foreland and follow it south to the Kenai and Kasilof Rivers south of East Foreland. The data are presented in Table 11. From this table it is quite apparent that most of these fish were bound for the spawning grounds south of East Foreland, and 46.5 per cent of the recoveries were made in the immediate vicinity of the Kenai and Kasilof Rivers. Five tagged fish were recaptured on the west shore of Cook Inlet at Point Harriet, West Foreland, and North Foreland. The northerly and westerly migration appears to be of slight importance as compared with the migration to the Kenai and Kasilof Rivers where important spawning grounds are located.

None of the cohos were recaptured.

TABLE 11.—*Returns from red salmon tagged at Nikishka Bay, July 21*

Locality of recapture	Number	Time in days
East shore of Cook Inlet:		
Windy Bay	[1] 2	------
Port Graham	1	1
Kachemak Bay—		
Nubble Point	1	1
Bluff Point	1	3
Kalifonski	1	5
Kenai	6	6–9
Salamato Beach	[2] 11	1–4
East Foreland	2	3
Nikishka Bay	1	6
Sunset Packing Co. No. 3	[1] 1	------
Sunset Packing Co. No. 1	[1] 2	------
East shore of Cook Inlet—Continued.		
Moose Point	2	3–4
Point McManus	1	3
West shore Cook Inlet:		
Point Harriet	2	2–3
North Foreland—		
Tyonek	1	2
Cottonwood Point	1	6
Three Mile Creek	1	4
Total	37	------
Per cent returned	15.1	------

[1] Reported taken before date of tagging.

[2] Two reported taken before date of tagging.

CONCLUSIONS

The percentages of recaptured tagged fish vary greatly with the species and to some extent with the locality and date of tagging. The data are presented in Table 12.

The percentages of tagged pink salmon recaptured are more uniform and are consistently higher, both in Prince William Sound and Cook Inlet, than those obtained for other species. The extremely high returns of pink salmon from the Cook Inlet experiments are most striking, because they are so much greater than any obtained in experiments conducted in other parts of Alaska. In an earlier report [3] it was pointed out that the percentage returns indicate, at best, a minimum percentage of the fish population captured in the commercial fishery because various factors are at work that keep the percentage returns of tagged fish below the percentage of untagged fish that are captured and with which the tagged fish were associated at the time of their liberation. The retention of tags as souvenirs by fishermen, and the failure of the cannery men to report tags received by them because the information required was wanting or for other reasons, are important factors in keeping down the known percentage of recaptures. In Cook Inlet, where 50 to 66 per cent of the released pink salmon were again taken, there can be no doubt that the actual drain on the resource is very much greater than those proportions; indeed it seems possible that the drain is so great as to menace the perpetuation of the supply.

TABLE 12.—*Percentage of tagged fish recaptured, 1929* [a]

Locality of tagging	Red	Pink	Chum	Coho
Prince William Sound:				
Montague Strait	11.1	35.6	------	------
Montague Point	------	36.1	------	------
Hinchinbrook Entrance	------	48.5	------	------
Knight Island Passage	------	35.5	------	------
Johnstone Point	16.7	34.2	18.6	33.3
Cook Inlet:				
Flat Island	24.2	51.8	24.9	16.7
Nubble Point	33.8	63.0	51.0	------
Nikishka Bay	15.1	------	------	------
Cape Starichkof	37.1	66.1	------	15.4

[a] Total number tagged, 4,143 total number recaptured, 1,613; percentage recaptured, 38.9 per cent.

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[3] Second experiment in tagging salmon in the Alaska Peninsula Fisheries Reservation, summer of 1923, by Charles H. Gilbert and Willis H. Rich. Bulletin, U. S. Bureau of Fisheries, Vol. XLII, 1926 (1927).

The returns obtained in Prince William Sound correspond very closely to those obtained from experiments in Southeastern Alaska.

Because the salmon runs in Cook Inlet and Prince William Sound are quite distinct, the experiments in those districts have been considered separately. In Prince William Sound 2,172 of the 2,250 fish tagged were pink salmon, the most important species in that district. The results may be summarized briefly as follows:

1. The pink salmon entering Prince William Sound through Montague Strait are distributed to virtually all parts of the sound. Two routes of migration are indicated; one is northeast along Montague Island to Hinchinbrook Entrance and from there to the bays and inlets along the east shore; and the other is northwest through Knight Island Passage to the streams on the west shore.
2. The pink salmon taken at Montague Point, like those in Montague Strait, are widely scattered to all parts of Prince William Sound. These fish may have entered the sound through Montague Strait, in which case some of the fish complete their migration to the spawning grounds on the east shore while others turn back over the route already covered along Montague Island and some continue to the spawning grounds on the west shore. Some of the fish taken here may also have entered Prince William Sound through Hinchinbrook Entrance in which case the liberated fish were a mixed lot. This seems more probable and would account for the scattering of the fish from Montague Point, whereas if only fish entering through Montague Strait had been liberated at Montague Point, the northeasterly migration alone would have been expected.
3. The distribution of fish tagged at Port Etches in Hinchinbrook Entrance was almost exclusively to the bays along the east shore of Prince William Sound.
4. Fish caught at Squire Island in Knight Island Passage are derived in large part from those entering Prince William Sound through Montague Strait and are bound mainly for the streams along the western and northern shores of those waters.
5. The fish passing Johnstone Point are bound chiefly for the streams on the east shore of Prince William Sound.
6. In most of the experiments there were no differences in the distribution of pink salmon tagged early in the season as compared with those tagged later in the season at the same place. Usually the fish tagged in the earlier experiments were recaptured after a longer period of freedom than those tagged later in the season—indicating a slower rate of travel.

In Cook Inlet, 1,893 salmon of all species were released during the 1929 tagging operations. Of this number 2 were kings, neither of which were recaptured; 788 were reds; 831 were pinks; 224 were chums; and 48 were cohos. The conclusions, based on data obtained from the four experiments conducted there, are as follows:

1. The distribution of the fish tagged at Flat Island varied with the species but was principally north in Cook Inlet. The red salmon tagged here on June 14 were taken in considerable numbers in the vicinity of English Bay, and a large percentage of all recaptures was made along the east shore of Cook Inlet south of Anchor Point, indicating that the red salmon passing Flat Island are largely bound for the smaller spawning streams in the lower inlet. Three reds were taken near Kodiak Island, and two were taken in Prince William Sound. The pinks, chums, and cohos were distributed along the east shore of Cook Inlet south of Anchor Point. Three pinks were taken in Prince William Sound.

2. The salmon taken at Nubble Point were distributed over much the same region as those tagged at Flat Island. A greater number of the red salmon, however, were taken north of Anchor Point. Three reds were taken near Kodiak Island and two were taken in Prince William Sound. As before, the pinks and chums were recaptured in greatest numbers in the bays of Kachemak Bay. It is interesting to note that most of the tagged salmon captured in localities other than Cook Inlet were tagged in the early part of the season.

3. The red salmon tagged at Cape Starichkof were chiefly distributed along the east shore of Cook Inlet, north to the Kenai and Kasilof Rivers. A few were taken in Kachemak Bay. The migration of the pink salmon was almost exclusively to Kachemak Bay. If any pink salmon do spawn in the streams north of Anchor Point, it is probable that the run is quite late, since only in the later experiments were recaptures of tagged pink salmon reported in the upper reaches of Cook Inlet, and then in numbers too few to indicate a definite migration.

4. The main route of migration of the salmon caught at Nikishka Bay is south along the east shore of Cook Inlet to the Kenai and Kasilof Rivers, where important spawning areas are located. Fish were also distributed along the east shore north of Nikishka Bay and along the west shore. The northerly migration seems to be of slight importance.

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AN EXPERIMENTAL STUDY IN PRODUCTION AND COLLECTION OF SEED OYSTERS[1]

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United States Bureau of Fisheries

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I. OYSTER CULTURAL PROBLEMS OF THE NORTH ATLANTIC WATERS

By PAUL S. GALTSOFF

INTRODUCTION

Of the many bottom organisms inhabiting our inshore waters, the American oyster occupies the most prominent place. From Cape Cod to the mouth of the Rio Grande it grows in great abundance in nearly every protected inlet, bay, or sound, forming in the localities where bottom and water conditions are favorable vast accumulations of live and dead shells, which cover areas of several square miles of sea bottom or extend for hundreds of miles along the tidal flats. In spite of such a striking abundance, many of the oyster-producing bottoms have become depleted, and the annual yield of oysters is declining. According to the statistics of the United States Bureau of Fisheries during the last 24 years, the annual production of market oysters has decreased 34 per cent. There may be several contributing factors that affect the annual crop of the oyster; but two of them—namely, the pollution of the inshore waters and the overfishing of the natural oyster bottoms—are undoubtedly the most important ones. Growth of cities along the Atlantic coast, accompanied by a tremendous development of industrial activity in the North Atlantic States, should be held responsible for the destruction of many natural resources of the ocean. With only a few exceptions, every city along the Atlantic and Gulf coasts has for years discharged untreated domestic sewage and trade wastes directly into the ocean. The effect of this deleterious and insanitary practice is that fish and shellfish in the vicinity of large cities have been either destroyed or made unfit for human consumption. Because of the present stringent sanitary regulations controlling the harvesting, handling, and marketing of shellfish, many thousands of acres of oyster-producing bottoms have been condemned, and formerly valuable grounds have become barren and worthless. On the other hand, intensive fishing on the natural oyster beds, coupled with the failure to return a sufficient number of shells to the grounds from which the oysters were taken, has resulted in the depletion of formerly productive natural bottoms. This decline in the productivity of natural oyster beds necessitated the introduction of various methods of intensive cultivation or oyster farming which at present are in operation in the North Atlantic States.

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The oyster industry in the United States dates back to the early days when the first settlers on the Atlantic coast of America began to take oysters from the natural beds. They found oysters growing everywhere, and the supply of them seemed to be inexhaustible. For a long time no attempts were made to regulate or restrict the fishing for oysters, and no efforts were exercised to replenish the supply of shells taken from the bottoms. The predominating idea was that nature takes care of itself and that the productiveness of the beds could be kept on a constant level without exercising any care or consideration as to the time of fishing or number of oysters taken.

With the increase of population in the United States and corresponding increase in the demand for oysters, the beds and reefs yielded less, and some of them became entirely unproductive. Disastrous results of excessive fishing and lack of care were noticeable first in the northern parts of the country, where, because of the climatic and hydrographic conditions, propagation of oysters does not take place regularly and setting of young oysters is often affected by adverse weather. Oyster beds in the Gulf of Maine and on Cape Cod were soon almost completely depleted, while the grounds in Rhode Island, Connecticut, and New York began to suffer from overfishing and employment of wasteful methods. The first restrictive measure, as far as can be ascertained, was passed in October, 1766, when the Assembly of East Greenwich, R. I., passed an "Act for the preservation of oysters," forbidding dredging or other methods of taking oysters except tonging. In 1784 the State Legislature of Connecticut passed a law empowering the coast towns to regulate the oyster fishery within their respective limits. The main aim of the regulations adopted by different towns in accordance with this law was to restrict the fishery and prevent the depletion of the bottoms.

The first attempts to transplant oysters were made about 1810 in New Jersey, when small oysters were taken from crowded reefs and planted on private bottoms (Stafford, 1913). In 1845 planting of oysters gathered from natural bottoms was carried out rather extensively in Connecticut. The next step in developing a method of oyster culture, which originated in the United States independently of those in Europe, was made in 1855, three years before Coste began his experiments on the cultivation of the European oyster in France; in this year for the first time, shells for catching spat were planted in the harbors and bays of the Connecticut shore of Long Island Sound. In 1870 planting operations were extended to deep water of Long Island Sound, so that the latter date marks the beginning of the elaborate system of oyster culture which is now in operation in northern waters.

At present nearly all available grounds for oyster planting in the northern waters have been leased to private ownership, and the exploitation of public natural beds has been almost completely discontinued. South of Delaware, the oyster industry is still based primarily on the exploitation of the natural public beds carried out under the supervision of the respective State governments. There is no doubt, however, that the increasing depletion of the natural beds will eventually result in their total destruction. Efforts exercised by different States for maintaining the productivity of public oyster bottoms by planting cultch and seed oysters at present are inadequate to prevent their gradual destruction, and there is no doubt that in the future the sounder system of oyster farming will be introduced in these waters.

The main difficulty which the oyster industry experiences in the northern waters consists in the lack of seed oysters due to insufficient and irregular setting. The most important seed-producing areas are located in the harbors or at the mouths of the rivers, where they are greatly affected by pollution. Many of them are so badly depleted and the number of adult oysters on them is so small that no more setting takes place in their vicinity. With the diminished oyster population in the seed-producing areas and the destructive effect of pollution on spawning and setting of oysters, a reliable supply of young oysters has become of great importance; in many localities it is the key to the future success of the oyster industry.

Two possibilities of rehabilitation of the industry are open for experimentation: The artificial propagation of oysters and the development of a better method of production and collection of seed oysters under natural conditions.

ARTIFICIAL PROPAGATION OF OYSTERS

After the first successful experiments in artificial fertilization and development of the eggs of the American oyster made by Brooks (1879), many attempts were made by various investigators to rear the larvæ to adult marketable sizes. Rice (1883), Winslow (1884), Ryder (1883), and Nelson (1901, 1904, 1907) tried different methods to keep the oyster larvæ alive and to bring them to a setting stage. In the reports published by these investigators, one finds the description of many difficulties encountered in the attempts to keep the minute, free-swimming organisms in jars and to provide them with the necessary supply of food. Although Ryder (1883) and Nelson (1901, 1904, 1907) were enthusiastic and believed in the practicability of their methods, their experiments did not pass beyond the laboratory stage and the artificially raised larvæ failed to set.

Later on, Wells, in 1920 and in the following years, working under the auspices of the New York State Conservation Commission (1923–1927) developed a method based on the use of a high-speed centrifuge; briefly speaking, the method is as follows: Artificially fertilized eggs are allowed to stay in the containers and develop into larvæ which are immediately transferred into 50-gallon stoneware jars. Once a day the content of the jar is passed through a high-speed centrifuge (De Laval multiple clarifier) and all the larvæ, after being collected in the bowl of the centrifuge, are transferred into a new jar filled with fresh sea water. After the larvæ attain a sufficient size to be retained by the fine wire screen (200 mesh to an inch) which was used during the changing of the water, they are kept in larger tanks where they finally set.

In 1924 Prytherch reported the result of his experiments on artificial propagation of oyster larvæ which had been carried out in 1923 at Milford, Conn. His method consisted in obtaining natural spawn from the oysters brought from the harbor and in keeping the oyster larvæ in a system of tanks; the changing of water was accomplished by a slow filtration through the porous artificial stone known as filtros. When the larvæ were about 10 days old, they could be held by means of fine screens of monel metal, which permitted a good flow of water. By this method Prytherch was able to produce several thousand seed oysters, which at the end of the summer were planted in Milford Harbor.

The question of whether the methods of artificial propagation developed since 1920 have reached such a perfection that they can be instrumental in rehabilitation of the industry, requires careful consideration. We read in the Annual Report of the Conservation Commission of the State of New York (1926, p. 125) that "as to the artificial propagation of oysters, the State feels that the problem has been solved." Unfortunately, the data given in the reports of the New York Conservation Commission for the years 1923 to 1927 referring to the number of artificially propagated oysters, fail to support this optimistic view. The present annual production of seed oysters in Massachusetts, Rhode Island, Connecticut, and New York amounts, according to the data of the United States Bureau of Fisheries, to 586,443 bushels valued at $657,392, or $1.13 a bushel. The actual figure of production is several times higher, because seed oysters produced and replanted by the same company are not recorded by the statistics, which include only oysters bought or sold on the market. Every serious attempt to put artificial propagation on a commercial scale must take cognizance of the two main factors—the quantity of seed oysters required by the industry and the cost of production. If, under the present conditions, no large quantities of seed oysters can be raised artificially or should the cost of artificial propagation be too high, then the problem is not solved. The difficulty only begins when one attempts to produce hundreds of thousands of bushels instead of a few thousand individuals.

Present methods of artificial propagation are expensive; the reports of the New York Conservation Commission give no information as to the possible cost of production and fail to show the total number of oysters produced by Wells's method. In the report of 1923 Wells states (p. 46) "that it has been impossible to determine accurately the yield of the operation. Altogether, approximately 10,000 were planted as set in the open waters. This represents, however, only a small portion of the total number of larvæ developed in the jars." From a practical point of view, the number of larvæ raised in jars or tanks has very little significance; the real test of the method is in the production of seed oysters; and, as one can judge from the report of the conservation department of 1923, the quantity of set produced by artificial propagation was equal to approximately one bushel. The conclusion seems to be inevitable that the practicability of the artificial propagation of oysters has not yet been demonstrated. Apparently, the New York Conservation Commission later on reached the same conclusion, because in the report of 1927 on page 340 it states: "The New York State oyster growers suffer from the lack of oyster set. Most of the seed used is brought in from Connecticut or other States. This is a big handicap, and a remedy is eagerly sought for." It is the author's opinion that present methods of artificial propagation of oysters are very valuable for laboratory and experimental study of the life history of the oyster, and it seems possible that in the future, when the procedure is simplified and the market price of seed oysters is higher, they can be made applicable for the practical needs of the industry. The immediate problem, however, is to find out means and methods to increase productivity in natural areas rather than to experiment in the line of artificial propagation.

SPAWNING AND SETTING OF OYSTERS

It has been known for many years that setting in northern waters is subject to wide fluctuations. Oyster growers have attributed the failure of oysters to set to various factors: Adverse weather conditions before and after the time of spawning, tides, currents, sedimentation, natural enemies, etc. In spite of a great variety of opinions expressed, the problem has been very little studied and the scientific literature on the subject is surprisingly meager. In discussing spawning, fertilization, and development of the oyster, the earlier investigators (Brooks, 1905; Ryder, 1881, 1882, 1883, 1884; and Stafford, 1913) gave but little attention to factors which might affect these phenomena. Nelson (1920), studying oyster culture problems in New Jersey waters, states that adult oysters do not spawn in New Jersey waters until the temperature has reached 21.1° C. (70° F.) and has maintained it for some time. Nelson believes that free-swimming larvæ are very sensitive to temperature changes and that a fall of several degrees in water temperature may cause the death of a large number of them. He states (op. cit., p. 9) that "a sudden fall in temperature during the setting period may completely inhibit the obtaining of a set."

Churchill (1920) and Gutsell (1924) state that oysters may spawn when the water reaches a temperature of 20° C. (68° F.) but that spawning proceeds at normal speed only when the water is 21.1° C. or above. According to Galtsoff (1930), temperature is not the only factor that controls the discharge of the sex products. Working under laboratory conditions, he found that the presence of sperm in the water induces the female oyster to spawn, the reaction taking place at the temperature of 20° C. and above. The eggs discharged by the female in turn induce the spawning of the males, and the process once started in one place continues throughout the oyster bed. Thus, the mutual stimulation of the opposite sexes plays an important rôle in the propagation of the oyster.

The failure of oysters to set was attributed not only to low temperature of water but also to the presence of enemies destroying the oyster larvæ. Nelson (1925) thinks that the ctenophore, *Mnemiopsis leidyi,* which occurs in great abundance in the inshore waters, is responsible for the disappearance of oyster larvæ and the absence of set in certain areas of New Jersey waters.

Our present knowledge of the biology of the oyster is not sufficient, however, to explain the rôle of the other factors which may affect spawning and setting. It is interesting to note, for instance, that in certain localities having an established reputation as excellent growing grounds, setting does not take place, in spite of high temperature of the water and the presence of large numbers of ripe adult oysters. Such, for instance, is Cotuit Bay in Massachusetts, where, according to the observations made by the author in 1926, a few oyster larvæ were found swimming in the water but they failed to attach themselves to shells planted in the bay. This was probably due to the fact that every shell in this bay in a period of a few days becomes covered with a slimy film formed by microscopic algæ, rendering its surface unsuitable for attachment.

One condition prerequisite for obtaining a good set is the presence of clean cultch, which should be planted shortly before the time of setting. In 1884 Winslow wrote, "Thousands of dollars would be saved annually by the oystermen if they would determine with any approximate accuracy the date when attachment of the young oysters would occur." It has been shown by Prytherch (1929) that time and intensity of setting can be predicted one month in advance; his method is based on a study of temperature and tidal conditions in a given body of water, on the determination of the number of spawners, and on an examination of the fullness of their gonad development.

The knowledge of the exact location of the setting zone is as important to the oyster culturist as is the knowledge of the time of setting. Observations carried out by Galtsoff and Prytherch in Long Island Sound, in waters of Massachusetts, in Great South Bay, N. Y., and along the coast of South Carolina and Georgia show that setting is often restricted to a very definite zone. For instance, in the tidal waters of South Carolina (Galtsoff and Prytherch) and Georgia (Galtsoff and Luce, 1930), it is confined to the zone between the tidal marks, while in the Great South Bay, N. Y., setting takes place from top to bottom. Analyzing the factors controlling setting in Milford Harbor, Prytherch (1929) arrives at the conclusion that the distribution of the setting zones can be correlated with tidal changes during the time of setting. He finds that in Milford Harbor the zone of the heaviest setting coincides with the level of low slack water. Corroborating evidence is found in the fact that no oyster larvæ swim about in the water when the velocity of the current is more than 18.3 centimeters (0.6 feet) per second. Whether the setting at a definite level is due only to the changes in velocity of the current during the tidal cycle or can be correlated with the changes in the composition of the sea water at different stages of tide, is a problem for further research in which the authors are engaged.

METHODS OF SPAT COLLECTION

One of the most popular methods of collecting spat or seed oysters consists in scattering clean shells over the bottoms where setting is expected. This method was first introduced in Connecticut in 1855 when, according to Brooks (1905, p. 105), shells were planted among the islands off the mouth of Norwalk River; since that time this method has been extensively employed in northern waters. In certain localities—for instance, Wellfleet Harbor, and in some parts of Long Island Sound—gravel and crushed stone have been planted with very satisfactory results. It was soon discovered that the time of planting is of great importance, since the shells after being submerged for even a few weeks may become covered with a slimy film that prevents the attachment of the oyster larvæ. It is of great importance, therefore, to begin the planting just before the time of setting. In Long Island Sound this is always done between the 15th of June and 15th of August. Inasmuch as the method of planting was fully described in the literature (Brooks, 1905, and Moore, 1897) it is not necessary to go into a detailed discussion of it. It is sufficient to state that the bottoms over which the shells are scattered must not be shifting and must be firm enough to support the weight of the shells. Obviously, the sand bars and soft mud bottoms are not suitable for the purpose and are never used for planting of shells.

Very elaborate methods of seed collection are employed in Europe, Japan, and Australia. They consist in using various types of collectors such as brush, crates of tiles (France), bundles of hagel and ropes (Italy), bamboo (Japan), and stacks of rocks (Australia), which are placed over the bottoms and in the tidal areas. For a description of these methods, the reader is referred to the papers of Brooks (1905), Kellogg (1910), B. Dean (1892–93), and Roughley (1925). In this country experiments with artificial spat collectors were carried out in 1880–1885 by Ryder (1887), who used tile and slate coated with the mixture of lime, sand, and cement. All of these methods require considerable labor, and the cost of both material and operation is rather high. They can be used only in the countries where labor is cheap and the price of oysters is high. Under American conditions, where labor is expensive and the market price of oysters is low, the foreign methods of cultivation are not practicable. The problem for American oyster culturists is to find an efficient but inexpensive and simple method of collecting seed oysters which would require the minimum amount of labor.

BRUSH COLLECTORS

Of various types of collectors, brush is the least expensive. The first use of brush in America was made in 1868 (Collins, 1891, p. 477) in the Poquonock River, Conn., when a farmer, after trimming his orchard and throwing the branches of the trees into the river, found them in the succeeding autumn covered with oysters. This suggested the employment of the method by others, and for several years it was known as the "brush" or "Poquonock" method. It was, however, only moderately successful and later was discontinued.

During the last 10 years several attempts were made to plant brush in Great South Bay, but the results were not entirely satisfactory; setting was generally light and only a small number of young oysters were found attached to twigs.

In the waters of North Carolina and Georgia, where setting is heavy and occurs between the tide marks, brush can be easily planted by sticking it into soft mud on the flats. The experiments with brush carried out in 1926 and 1928 in North Carolina and Georgia (Galtsoff and Luce, 1930) have demonstrated both the possibilities and the limitations of this method.

WIRE BASKETS

Since the beginning of shell planting in 1855, only a few attempts were made to improve this method. In 1910 Belding (1911), studying the setting of spat in Wellfleet Harbor, Mass., used collectors consisting of from one-half to one bushel of shells placed between the tide lines and covered with galvanized wire netting of 1-inch mesh, securely fastened to the bottom by four short stakes. The height of the shell heap was 8 inches; the collectors were used only for a study of the intensity and distribution of setting; and the method was not tried on a commercial scale. In 1925 Capt. C. E. Wheeler, of the Connecticut Oyster Farms Co., suggested the use of wire baskets filled with oyster, clam, and mussel shells and placed on the flats. Experiments were carried out by Prytherch at Milford, Conn., and proved a success (Prytherch, 1930). Each of the shells on the top, bottom, and sides of the baskets was covered with from 100 to 200 spat; those in the layer just inside caught from 10 to 50 spat each, and those in the very center from 2 to 10 spat each. It was evident that the shape of the basket should be changed to enable the oyster larvæ to penetrate more easily and attach on the shells in the center.

CRATE COLLECTORS

In 1926 an inexpensive shell container was designed for this purpose. It is triangular in shape (fig. 1) and is constructed of spruce lath spaced 1½ inches apart. Three square sides, each 2 by 2 feet, are wired together after the bottom is put in place. The bottom is 6 inches above the ground, but the length of the legs can be increased, if necessary. The capacity of the container is 2 bushels, and it covers 2 square feet of bottom. To protect the wood from the attack of shipworms and other wood-boring organisms, the lath is coated with a mixture of quicklime and sea water, to which is added enough fine sand or mud to give the consistency of thick cream; after this treatment, the crate can be used several times.

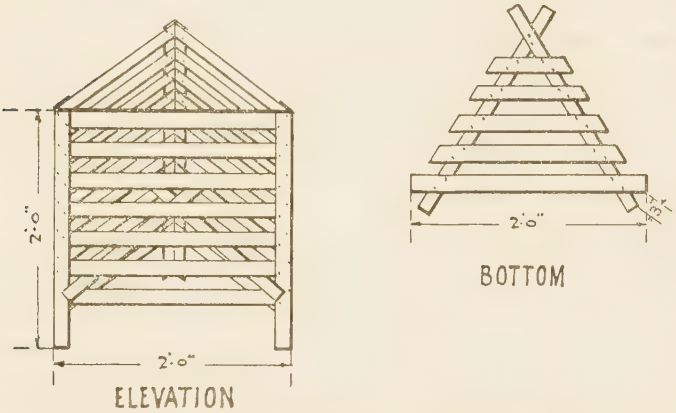


FIGURE 1.—Lath container (crate) for oyster shells. The three sides are constructed the same and are wired together after the bottom is put in place. Laths are spaced 1½ inches apart

Planting of the containers is a simple operation and can be carried out in different ways, depending on local conditions. Containers already filled with shells can be delivered at high tide on the grounds and thrown overboard; or in case of planting on tidal flats, the containers are stuck in the bottom and filled with shells afterwards. In the case of very soft bottom, the length of the legs can be correspondingly increased.

Experiments with lath containers were carried out in 1925 and 1926 in Milford Harbor, Conn., Wellfleet Harbor, and Wareham River, Mass. The results of these experiments have shown that, in order to insure better penetration of the oyster larvæ, the size of the container should be reduced. Some of the containers planted in Wellfleet Harbor and Wareham River, where they were exposed to strong wave action, were destroyed or washed away. At the same time, the experiments have demonstrated that by using the containers the catching of seed oysters over a given area of bottoms can be increased materially.

WIRE BAGS

At the suggestion of Prytherch, a new type of shell container was built and tested out in 1927. The container consisted of a bag of chicken wire having a mesh of 1½ to 2 inches and was filled with oyster, scallop, clam, and sea scallop shells. The wire bags had a capacity of 1 bushel and were cylindrical in shape, with a length of 36 inches and a diameter of 12 inches. The method employed in constructing the bags and filling them with shells is shown in Figure 2. The wire mesh was purchased in 24-inch rolls and then cut into pieces 3 feet long. (Fig. 2, Nos. 1 and 2.) Each piece of wire was then folded lengthwise and the ends closed either by twisting the wires together or by weaving a short piece of No. 18 annealed wire through them. (Fig. 2, Nos. 3 and 4.) The wire bags are now ready to be filled, and in this form they can be easily stored until it is time for shell planting. The filling of the bags was accomplished easily by placing them in an oblong wood box, 36″ by 8″ by 8″, and adding sufficient shells to fill them to the top. The bags were then closed tightly by drawing and weaving the edges together with galvanized, annealed wire No. 18. The bags of shells can be handled roughly without breaking open. They can be set out singly or can be stacked in tiers several feet high, thereby greatly increasing the quantity of cultch that can be planted on a given area of bottom.

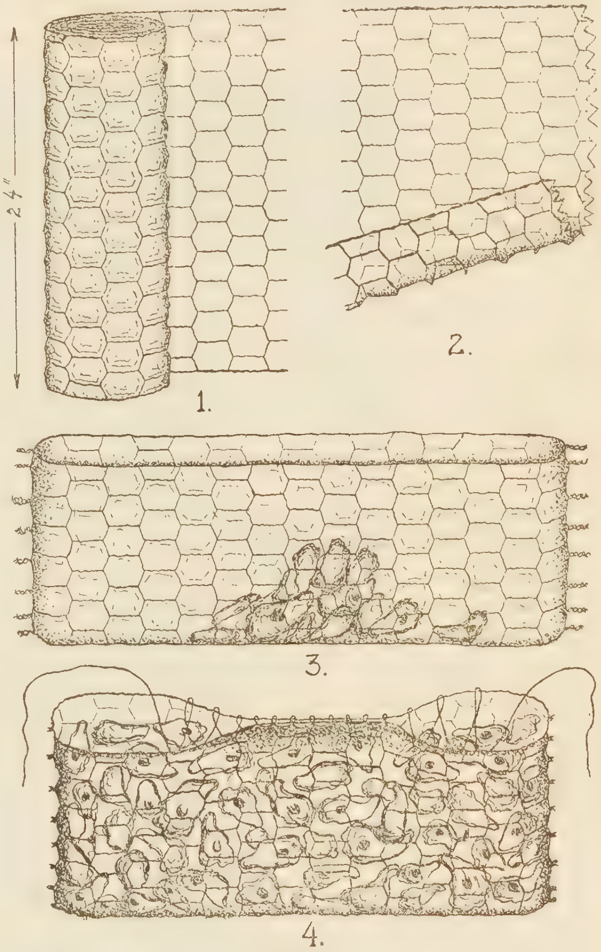


FIGURE 2.—Method of construction of wire bag collector. (Explanation in text)

The cost of the material for each bag at current retail prices was 5 cents for those of 2-inch mesh and slightly more for 1½-inch mesh. The oyster or scallop shells which were used cost 10 cents per bushel. The cost of the labor employed in making the bags, filling, and planting them averaged approximately 10 cents per bag, which gives a total cost of 25 cents for each bushel of shells that was planted. The method of making and filling the bags can be greatly simplified and the cost reduced when the operations are carried out on a commercial scale. Experiments with the shell bags were made at Onset, Mass., Milford, Conn., and Great South Bay, Long Island, in 1927 and 1928. The arrangement and position in which the bags were placed and other details of the experiments are given under each locality, together with the results that were obtained.

The method of collecting spat in lath containers or in wire bags is based on the assumption that with the present method of scattering shells over the bottom only a small percentage of oyster larvæ present in the water finds a place of attachment, and that the majority of them perish. The main problem to increase the production of seed oysters is, therefore, to find the method whereby the natural supply of larvæ will be fully utilized. This can be accomplished by increasing the amount of cultch planted, thereby increasing the area suitable for attachment, and by utilizing the three dimensions of the setting zone by planting shells in bags or crates. A study of the distribution of the setting zones in various localities reveals the fact that there is always a level or zone where setting is the heaviest. The question of what causes the oyster larvæ to set in a definite zone is a very complex one and requires further investigations; but the determination of the zone of setting in any given locality presents no difficulty, as in most of the cases a careful examination of the bottoms and various submerged objects or structures allows one to determine it very accurately. (Fig. 3.) Obviously this zone should be utilized to its maximum capacity.

It is known that setting in northern waters is rather irregular; good years are followed by blank ones when there is no setting at all or when it is so light as to be of no commercial value. Examination of the setting regions discloses, however, the fact that there are certain localities where setting occurs regularly every year. Such are, for instance, Onset Bay and Wareham River in Massachusetts. It is logical that these areas should be more thoroughly utilized for the production of seed oysters. In the localities where setting continues for a period of 2 or 3 weeks, the collectors which had already caught a sufficient number of spat can be replaced by new ones, and in this manner the productivity of the given area may be increased and the intensity of setting on the cultch can be regulated.

One important factor governing the propagation of oysters is frequently forgotten or overlooked. It is the presence of a sufficient number of adult oysters (spawners) in the vicinity of the setting grounds. It is obvious that the abundance of spat is primarily dependent on the quantity of eggs discharged into the water. Inasmuch as the fertilization of the oyster egg takes place outside of the organism and is a matter of chance, there must be a sufficient number of ripe males and females to insure the abundance of the oyster larvæ in a given body of water. It is estimated that the spawning bed should contain not less than 500 bushels of spawners per acre.

Spawning and setting of oysters are controlled by a great number of environmental factors of which the temperature, salinity of the water, and the tidal currents are of great importance. Hence, knowledge of these conditions is essential for the success of an experimental study of oyster culture. In the following papers considerable space is given to the description of the localities where the experiments were carried out, together with the records of temperature, salinity, and velocity of tidal currents. These experiments were carried out under the general direction of P. S. Galtsoff in Wareham River, Mass., in Onset Bay, Mass., in Milford Harbor, Conn., and in Great South Bay, N. Y. These localities represent the different ecological conditions which one encounters in the northern section of the Atlantic coast. It was the author's intention to give a fair trial to the new method of spat collecting and to determine by a comprehensive study both its advantages and limitations.

The experimental work was greatly facilitated and in many instances made possible by the excellent cooperation given by the oystermen. It is a pleasure to express our thanks and to acknowledge the help rendered by W. H. Raye, president, and Capt. C. E. Wheeler, manager, of the Connecticut Oyster Farms Co., and to Messrs. Schroeder and Besse, of Onset, Mass.

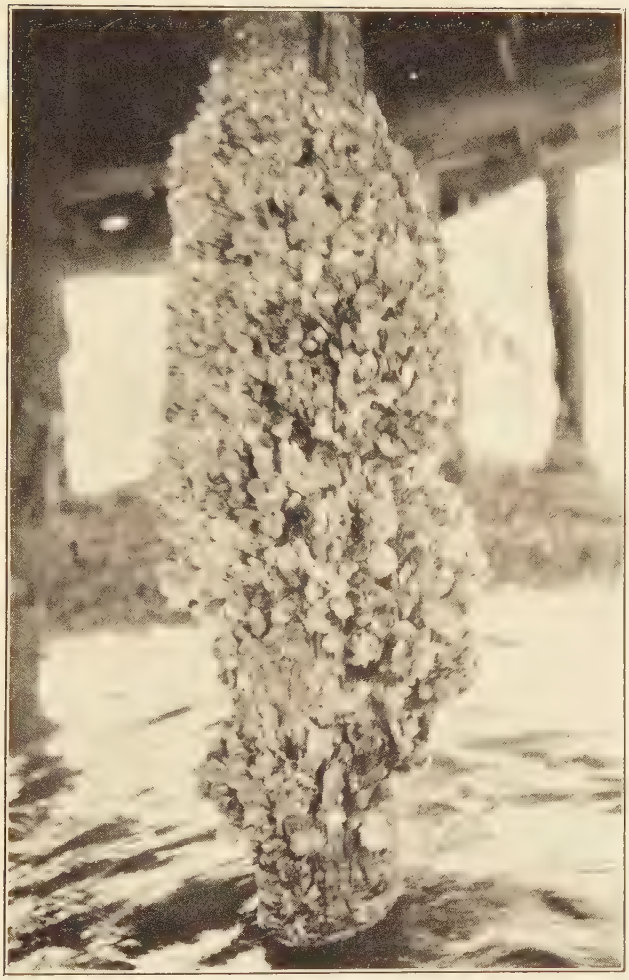


Figure 3.—Zone of heaviest setting. Wharf at low tide, Beaufort, S. C

II. OBSERVATIONS AND EXPERIMENTS IN SEED-OYSTER COLLECTION IN WAREHAM RIVER, MASS., 1926

By PAUL S. GALTSOFF

INTRODUCTION

The body of water known as Wareham River is a small oyster-producing area in the State of Massachusetts, where the oyster industry has been carried on since colonial days. Oyster production in this region has never attained large proportions, and in the early days consisted in the exploitation of the natural beds. Apparently they were soon depleted, because in 1775 the town meeting of Wareham voted that there should be no shellfish nor shell sold or carried out of town (Ingersoll, 1881). Later on, planting of shells was introduced, and it is known from the court records that in 1840 oyster cultivation was carried on in Wareham River. At present, the oyster industry in Wareham consists mainly in the production and selling of seed oysters, only a small number of which are grown locally. The operations are carried out by individual oystermen, who receive small grants from the town. The average size of the grant is about 2 acres. Unfortunately, the grants are not well described and for the most part unsurveyed. According to Belding (1909, p. 155), in 1909 the total area of grants approximated 1,000 acres, but only 196 acres were under cultivation. The annual production of seed oysters is around 20,000 bushels (Belding, 1909; Division of Fisheries and Game, 1925, p. 58).

Two reasons influenced the selection of this locality for the experiments with spat collectors. First, the character of the oyster business consists mainly in producing seed oysters which are sold during the fall before the onset of cold weather; second, as could be ascertained from local oystermen, setting occurs here very regularly, and during the last 25 years there were only a few years when the oysters failed to set. The possibility of increasing the productivity of seed oysters per acre is of great importance for localities like Wareham River, where the area of bottoms suitable for shell planting is very limited. On the other hand, the regularity of setting affords opportunity for an experimental study with spat collectors.

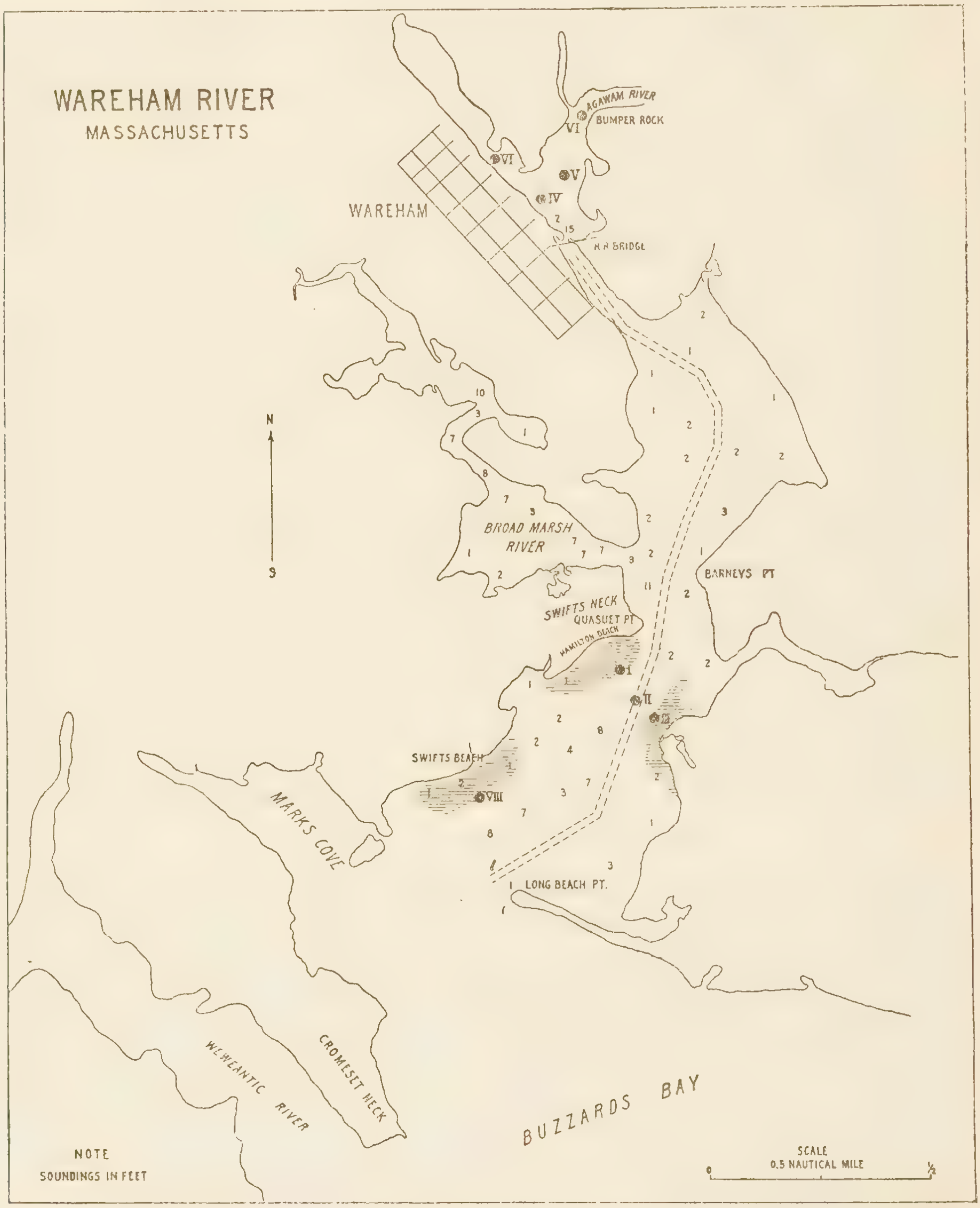
DESCRIPTION OF THE LOCALITY

Wareham River forms the extreme northwestern corner of the head of Buzzards Bay (fig. 4); the town of Wareham is located on its west bank, approximately 2 miles above its mouth. The entrance to the river from the bay is obstructed by a sand bar known as Long Beach, extending for about 700 yards in a WNW. direction, and by extensive shoals and numerous ledges through which a dredged channel 12 feet deep and 100 feet wide leads to the town. The channel ends at the railroad bridge, where the river is about 75 yards wide. Above the bridge the river expands again and is joined by the shallow Agawam River, partially surrounded by marshes.

The depth in Wareham River, excluding the 12-foot channel, between Long Beach and the railroad bridge, varies from 1 to 11 feet at mean low water. The areas having a depth from 5 to 11 feet are, however, very small, the greater portion of the river being formed by shoals and bars from 1 to 4 feet deep. The bottom is generally hard in the southern half of the river between Barneys Point and Long Beach Point (fig. 4) and sticky and soft mud along both sides of the channel north of the line connecting Barneys Point and the mouth of Broad Marsh River. All over the bottom, excepting the shoals that are exposed at low water, eelgrass grows prolifically.

Shifting bottoms are found on the western shore of the river along Swifts Beach, around Long Beach Point, and at the entrance to the river.

Excepting the sand bars and flats exposed at low tide, oysters are found scattered all over the area. There was a continuous oyster bed in the upper part of the river, above the railroad bridge, which at present is greatly depleted, but scattering oysters can be found in this portion of the river as far as Bumper Rock. (Fig. 4, Station VII.)


WAREHAM RIVER
MASSACHUSETTS
AGAWAM RIVER
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VI
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II
III
SWIFTS BEACH
VIII
MARKS COVE
LONG BEACH PT.
CROMESET NECK
WEWEANTIC RIVER
BUZZARDS BAY
NOTE
SOUNDINGS IN FEET
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 4.—Wareham River, Mass. Shaded areas indicate locations where crates were planted. Roman figures denote stations

Setting in Wareham River takes place in the area between the tidal marks on both shores of the river. Planting of shells usually begins in the latter part of June and is completed before the 10th of July. The flats exposed at low tide are carefully cleaned from accumulations of eelgrass and other débris, and scallop shells are distributed evenly over the exposed areas. The shells are deposited very densely and raked in such a manner that they stand on the edges, thus affording the greatest surface for the attachment of the larvæ. Planting of shells never extends below low-water mark.

For the experiments with spat collectors the locations indicated as Stations I, III, and VIII (fig. 4) were chosen. Station III was located on the grounds where scallop shells were planted; Stations I and VIII were located along the western shore where no planting was done in 1926, although a certain amount of shells was left from previous operations. Field observations at Wareham were carried out during the summer of 1926 by R. W. Crozley, under the direction of the author.

TEMPERATURE OF THE WATER

Present observations cover a period of 40 days (July 9 to August 17, 1926) when temperature readings were made at 8 different stations in the river. (Fig. 4.) Before discussing the results of these observations, it is interesting to note that there were only slight differences between the temperatures in the upper part of the bay and at its mouth; in other words, that the horizontal distribution of temperature along the whole area of Wareham River was nearly uniform. This is clear from an examination of Figure 5, where temperature readings taken at the surface of the water between 9.50 a. m. and 11 a. m. of August 25 are shown with the figures of salinity. One will notice that the temperature in the upper part of the river above Barneys Point was approximately 0.5° C. higher than that in the lower part of the river. These observations were made on a calm, warm day.

In a shallow body of water with a considerable range of tide, the hourly fluctuations of temperature may be quite large. The best method to study them is by installing a thermograph and obtaining a complete record for a given period of time. Unfortunately, because of the local conditions this was not feasible, and our records of hourly fluctuations of temperature refer only to three days, August 14, 28, and September 28, when readings were made at Station II every half hour between 5.20 a. m. and 6.30 p. m. The results of these observations are presented in Tables 1, 2, and 4. As can be seen from an examination of these tables, the greatest fluctuation in temperature (1.7° C.) was observed on August 28.

TABLE 1.—*Hourly fluctuations in the temperature and salinity*[1] *of water in Wareham River, August 14, 1926*[2]

Time	Station II		Station VIII[3]	Time	Station II		Station VIII[3]
	Temperature, ° C.	Salinity, per mille	Salinity, per mille		Temperature, ° C.	Salinity, per mille	Salinity, per mille
12.30 p. m.	26.0	28.31	28.36	4 p. m.	26.0	26.06	26.68
1 p. m.	26.0	28.49	28.69	4.30 p. m.	26.0	26.25	27.72
1.30 p. m.	26.1	28.53	28.85	5 p. m.	26.2	26.58	27.25
2 p. m.	26.5	28.36	28.98	5.30 p. m.	26.3	26.98	27.30
2.30 p. m.	27.0	24.66	27.00	6 p. m.	26.0	28.26	28.26
3 p. m.	26.0	25.39	26.00	6.30 p. m.	25.7	27.07	27.23
3.30 p. m.	26.2	25.33	26.20	7 p. m.	25.6	27.03	27.23

[1] Temperature and salinity readings given in this table were taken at the surface.
[2] High water at 11.55 a. m.; low water at 4.51 p. m. Range of tide, 2.8 feet.
[3] Observations at Station VIII were made 5 minutes after time shown.

Daily fluctuations of water temperature observed during July and August, 1926, are shown in Figure 6, together with the maximum and minimum air temperatures

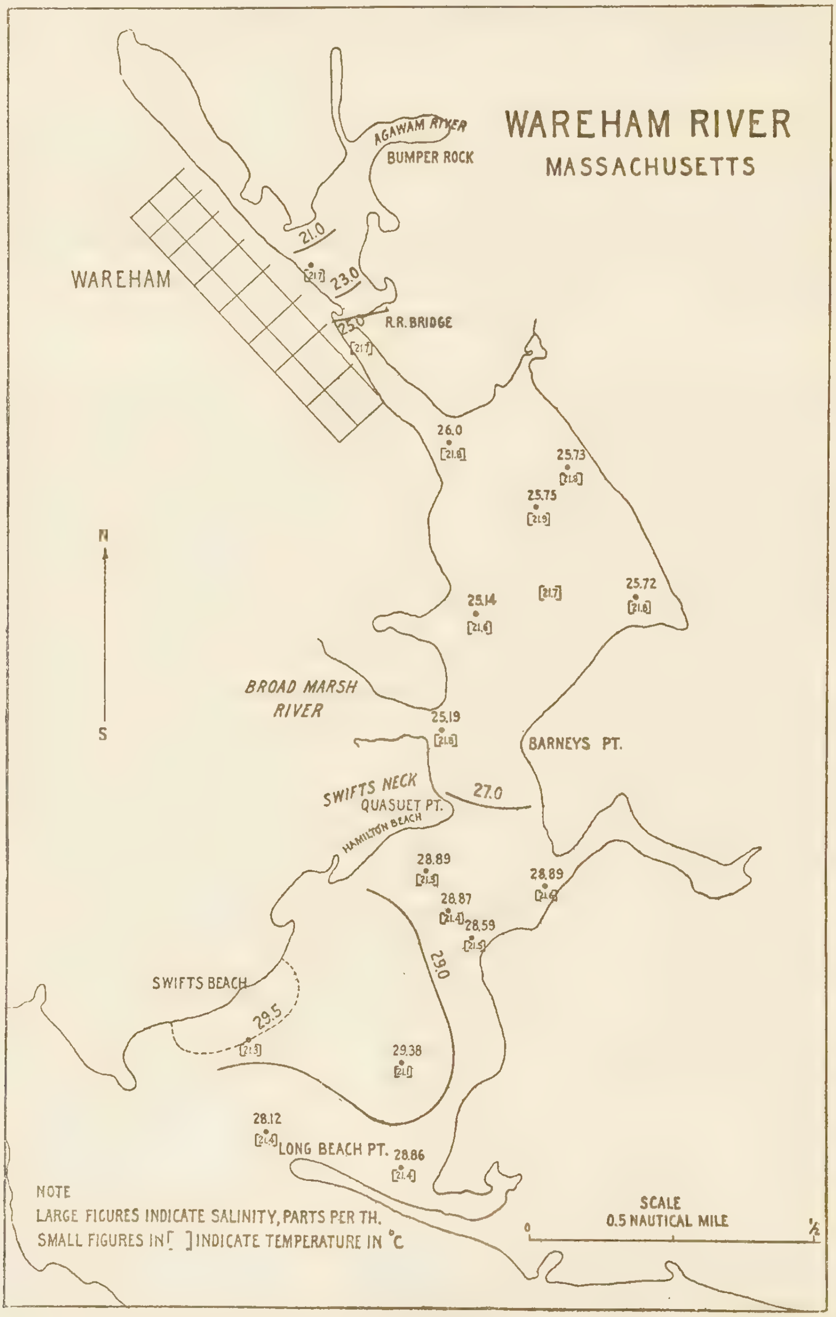
WAREHAM RIVER
MASSACHUSETTS
AGAWAM RIVER
BUMPER ROCK
WAREHAM
21.0
[21.7]
23.0
25.0
R.R. BRIDGE
[21.7]
26.0
[21.8]
25.73
[21.8]
25.75
[21.9]
N
S
25.14
[21.6]
[21.7]
25.72
[21.8]
BROAD MARSH RIVER
25.19
[21.8]
BARNEYS PT.
SWIFTS NECK
QUASUET PT.
HAMILTON BEACH
27.0
28.89
[21.5]
28.89
[21.6]
28.87
[21.4]
28.59
[21.5]
29.0
SWIFTS BEACH
29.5
[21.3]
29.38
[21.1]
28.12
[21.4]
LONG BEACH PT.
28.86
[21.4]
NOTE
LARGE FIGURES INDICATE SALINITY, PARTS PER TH.
SMALL FIGURES IN [ ] INDICATE TEMPERATURE IN °C
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 5.—Horizontal distribution of temperature and salinity in Wareham River, August 25, 1926, at low water. Isohalines are shown in heavy line. Large figures indicate salinity, per mille; small figures are degrees C.

recorded by the United States Weather Bureau station at East Wareham. By examining Figure 6, one can see that there were two distinct temperature maxima, the first on July 23 and the second on August 4, when the temperature of the water reached 27.0° C. and 28.0° C., respectively. The general rise and fall of the water temperature followed the fluctuations of the air temperature. It is interesting to note that the curve of water temperature approaches the curve of the maximum air temperature, although, as one should expect, the fluctuations in the temperature of the water are not so pronounced as those of the air temperature. The vertical distribution of water temperature was rather uniform; slight differences between top and bottom temperatures, not exceeding 1.5° C. (July 23), were noticeable only in the channel.

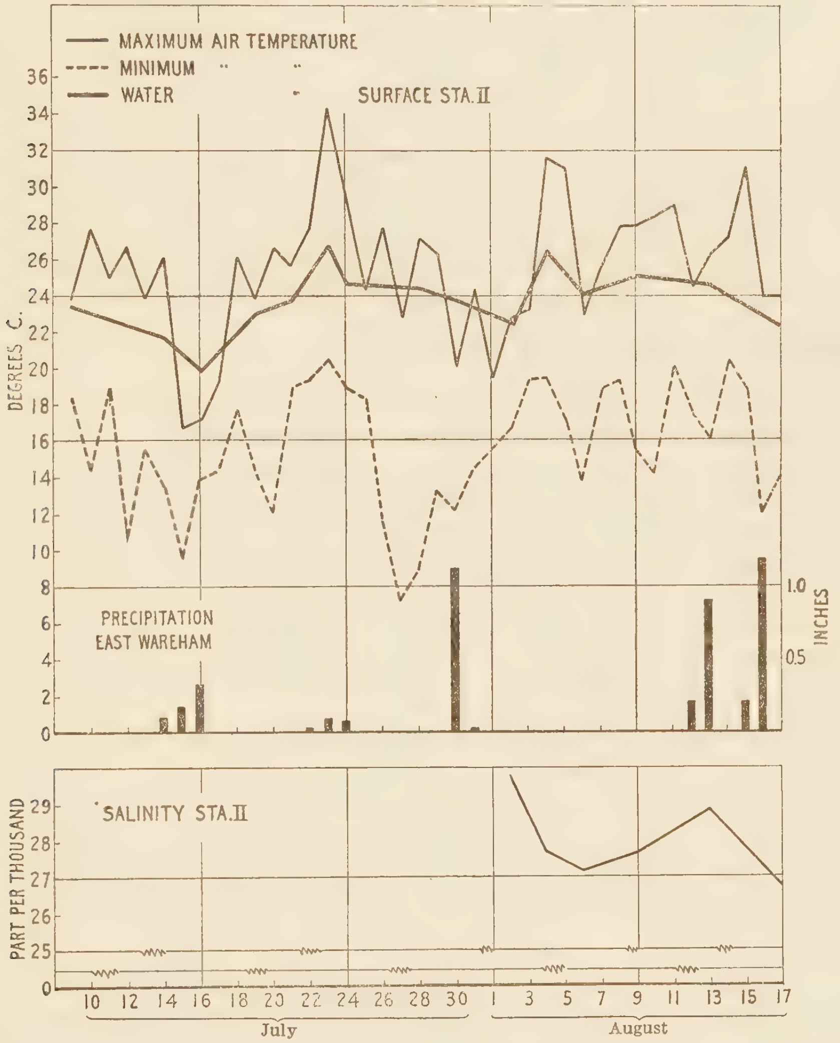

FIGURE 6.—Maximum and minimum air temperature, precipitation, temperature, and salinity of water in Wareham River, July–August, 1926

SALINITY OF THE WATER

The salinity of water in Wareham River gradually decreases from about 30 per mille at its mouth to about 21 per mille in the upper part of the river near the railroad bridge. After rainy days, August 13 to 16 (fig. 6, Table 3), the salinity dropped to 7 per mille in the upper part of the river (Agawam River) and 26 at its mouth.

TABLE 2.—*Hourly fluctuations in the temperature and salinity of water in Wareham River, August 28, 1926* [1]

Time	Station II			Station I [2]		Time	Station II			Station I [2]	
	Temperature, ° C. (surface)	Salinity, per mille		Temperature, ° C. (surface)	Salinity per mille (surface)		Temperature, ° C. (surface)	Salinity, per mille		Temperature, ° C. (surface)	Salinity, per mille (surface)
		Surface	Bottom					Surface	Bottom		
9.30 a. m.	20.3	28.30	29.13	20.6	28.77	2 p. m.	21.6	26.56	29.74	21.1	29.56
10 a. m.	20.4	28.59	28.96	20.7	28.82	3 p. m.	21.7	27.06	28.55	21.2	28.80
10.30 a. m.	20.3	--------	29.42	--------	--------	3.30 p. m.	21.7	--------	28.24	--------	--------
11 a. m.	20.3	29.57	29.46	20.5	29.37	4 p. m.	21.7	27.81	28.17	21.2	29.17
11.30 a. m.	20.6	--------	29.75	--------	--------	4.30 p. m.	21.7	--------	27.85	--------	--------
12 noon	20.8	29.90	29.97	21.2	29.22	5 p. m.	21.7	27.36	27.39	22.0	28.96
12.30 p. m.	21.2	--------	29.91	--------	--------	5.30 p. m.	21.8	--------	27.81	--------	--------
1 p. m.	21.3	29.52	29.90	21.0	29.45	6 p. m.	22.0	27.59	29.90	22.4	29.78
1.30 p. m.	21.3	--------	29.96	--------	--------	6.30 p. m.	--------	--------	--------	22.4	29.51

[1] High water at 12 (noon); low water at 5.23 p. m. Range of tide, 4.2 feet.

[2] Observations at Station I were made 5 minutes after time shown.

The horizontal distribution of the water of different concentrations of salt does not remain constant but is subject to fluctuations, depending on the stage of the tide and river discharge. A good idea of the distribution of salinities in relation to the stage of the tide can be gained by examining Figures 5, 7, and 8, showing the results of the observations made on the calm days of August 25 and September 27, when there was no mixing of water caused by the action of wind. All the observations were made within 1 hour and 10 minutes at high or low water. By comparing Figures 7 and 8, one can notice that in the upper part of the river the difference in the salinity due to the stage of the tide was 3 per mille, and that at high tide the salinity of 30 per mille extended over the entire lower half of the river.

TABLE 3.—*Temperature and salinity of the water at the surface of Wareham River, July to August, 1926*

Date	Station I		Station II		Station III		Station IV		Station V		Station VI		Station VII		Station VIII	
	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille
July 9	24.2	-------	23.5	-------	24.0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
July 14	22.1	-------	21.8	-------	21.8	-------	22.0	-------	22.1	-------	-------	-------	-------	-------	-------	-------
July 16	19.8	-------	19.9	-------	20.1	-------	20.1	-------	19.0	-------	-------	-------	-------	-------	-------	-------
July 19	23.0	-------	23.0	-------	23.0	-------	23.2	-------	23.0	-------	-------	-------	-------	-------	-------	-------
July 21	24.6	-------	23.7	-------	23.7	-------	23.8	-------	23.4	-------	-------	-------	-------	-------	23.6	-------
July 23	27.0	-------	26.8	-------	27.8	-------	26.7	-------	-------	-------	26.2	-------	26.6	-------	28.3	-------
July 26	24.0	-------	24.7	-------	25.2	-------	24.7	-------	25.3	-------	24.4	-------	24.7	-------	25.0	-------
July 28	25.2	-------	24.4	-------	25.0	-------	23.6	-------	25.9	-------	24.0	-------	24.1	-------	24.8	-------
July 30	22.0	-------	22.8	-------	22.6	-------	22.3	21.18	23.4	-------	22.3	-------	22.3	-------	22.6	-------
August 2	22.2	28.04	22.5	29.76	-------	-------	22.2	25.28	22.2	25.30	22.3	13.70	22.1	10.72	22.0	-------
August 4	28.0	27.14	26.5	27.70	27.5	26.88	26.7	17.13	28.2	14.72	28.0	9.83	-------	18.51	-------	-------
August 6	24.0	28.82	24.0	27.17	-------	-------	24.3	22.44	24.2	24.60	24.3	21.02	24.2	-------	-------	-------
August 9	25.3	28.16	25.0	27.66	25.2	28.94	25.8	21.26	25.2	27.93	25.2	21.28	25.3	18.22	26.0	27.81
August 13	24.8	29.58	24.5	28.86	24.3	29.18	26.0	23.17	26.0	23.15	25.7	20.25	-------	-------	25.2	29.32
August 17	22.3	26.87	22.2	26.77	21.5	-------	23.0	-------	23.0	7.12	23.0	7.12	-------	-------	22.3	-------

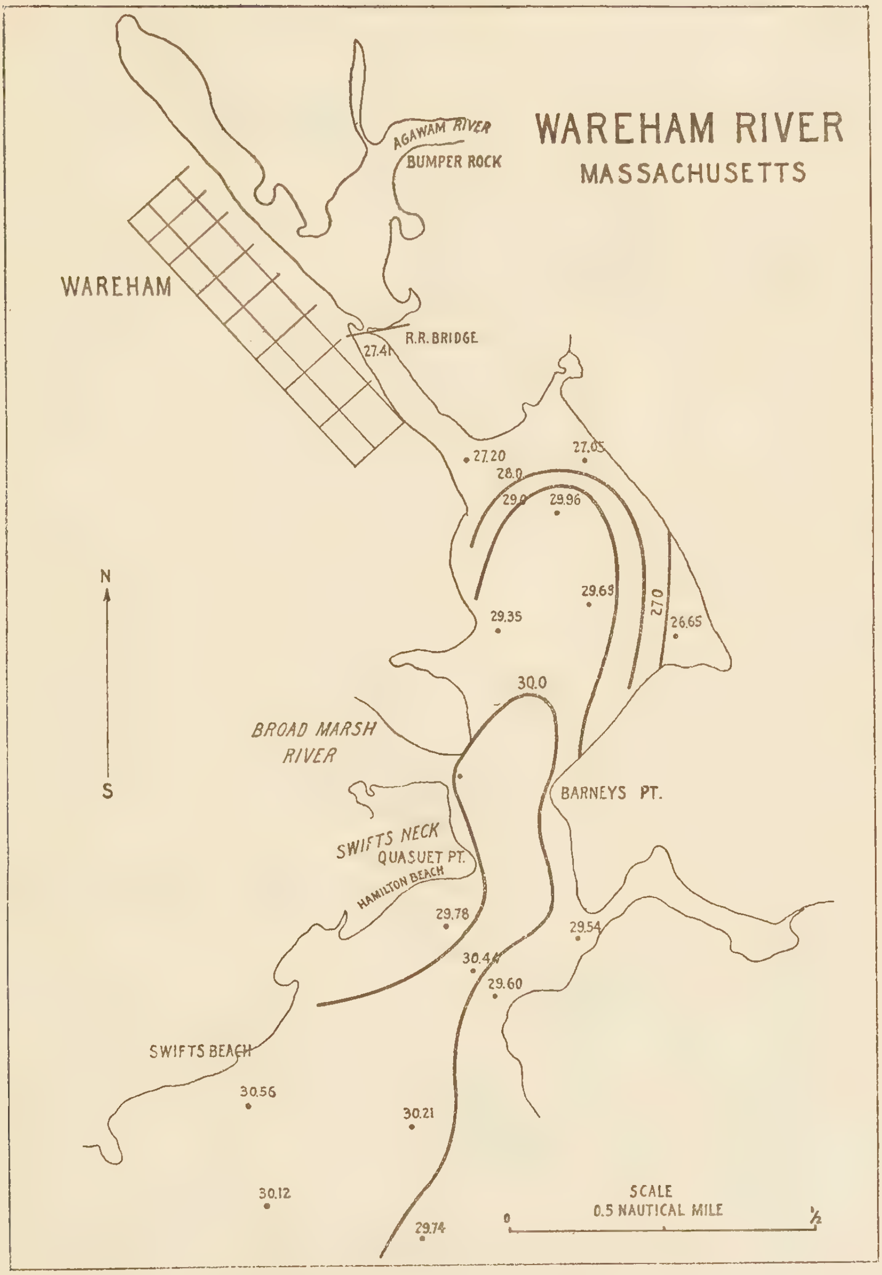
WAREHAM RIVER
MASSACHUSETTS
AGAWAM RIVER
BUMPER ROCK
WAREHAM
R.R. BRIDGE
27.41
27.20
27.65
28.0
29.0
29.96
29.69
27.0
26.65
29.35
30.0
BROAD MARSH RIVER
BARNEYS PT.
SWIFTS NECK
QUASUET PT.
HAMILTON BEACH
29.78
29.54
30.44
29.60
SWIFTS BEACH
30.56
30.21
30.12
29.74
N
S
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 7.—Horizontal distribution of salinity (per mille) in Wareham River, September 27, 1926. High water, 12.05 p. m. to 1.10 p. m.

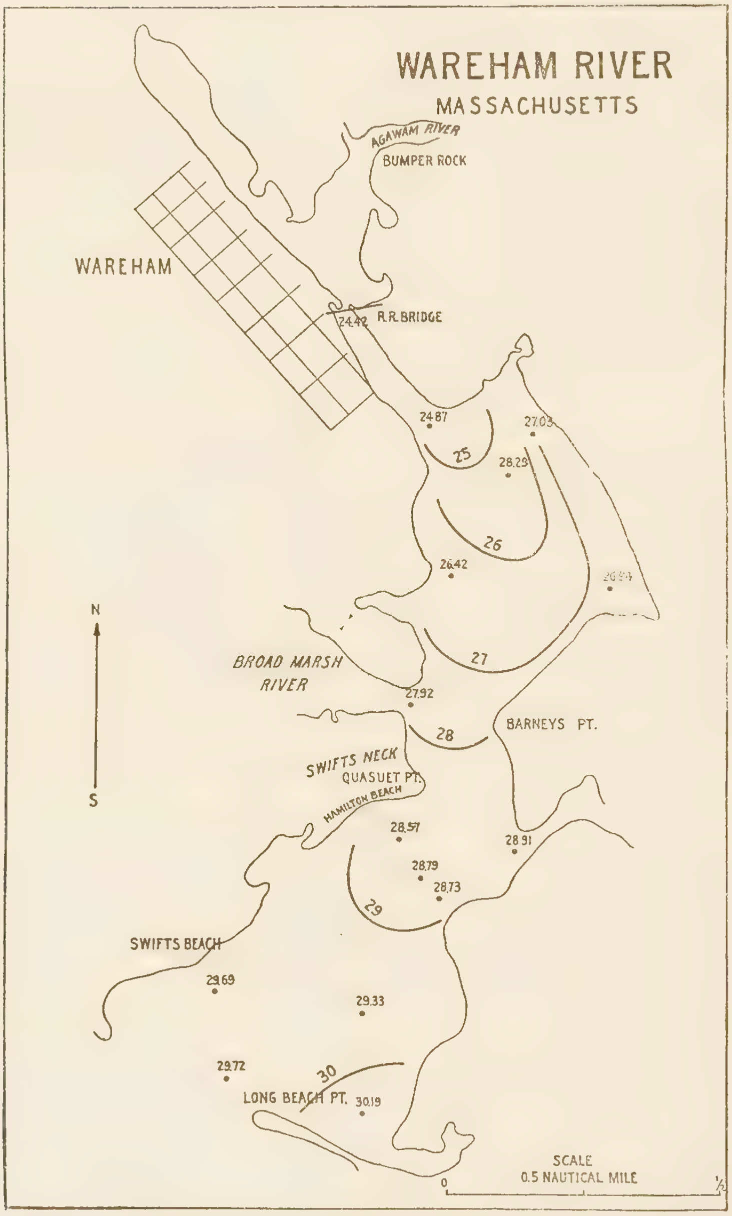
WAREHAM RIVER
MASSACHUSETTS
AGAWAM RIVER
BUMPER ROCK
WAREHAM
R.R. BRIDGE
24.42
24.87
27.03
25
28.29
26
26.42
26.94
N
S
27
BROAD MARSH RIVER
27.92
28
BARNEYS PT.
SWIFTS NECK
QUASUET PT.
HAMILTON BEACH
28.57
28.91
28.79
28.73
29
SWIFTS BEACH
29.69
29.33
29.72
30
LONG BEACH PT.
30.19
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 8.—Horizontal distribution of salinity (per mille) in Wareham River, September 27, 1926. Low water, 6.00 p. m. to 7.05 p. m.

TABLE 4.—*Temperature, velocity of the current, and salinity during flood tide in Wareham River, September 28, 1926* [1]

Time [2]	Station II, channel				Station I	Station III	
	Temperature, ° C. (surface)	Current [3] Surface	Current [3] Bottom	Salinity, per mille (surface)	Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)
5.50 a. m.	17.5	3.0	15.2	28.69	------	------	28.91
6.20 a. m.	17.5	6.1	18.3	28.73	0	0	28.86
6.50 a. m.	17.5	0	12.2	28.86	0	3.0	28.87
7.20 a. m.	17.8	18.3	18.3	28.84	3.0	0	28.87
7.50 a. m.	17.5	18.3	18.3	28.96	3.0	0	28.71
8.20 a. m.	17.5	6.1	12.2	29.33	3.0	3.0	28.82
8.50 a. m.	17.5	6.1	12.2	29.01	6.1	6.1	29.15
9.20 a. m.	17.5	18.3	15.2	29.51	6.1	3.0	29.46
9.50 a. m.	17.5	30.5	24.4	29.46	6.1	3.0	29.52
10.20 a. m.	17.5	12.2	9.1	29.63	6.1	3.0	29.66
11.20 a. m.	17.4	15.2	15.2	29.78	6.1	3.0	29.75
11.50 a. m.	17.5	24.4	18.3	29.80	6.1	3.0	29.96
12.20 p. m.	18.0	21.3	18.3	29.85	0	3.0	30.26
12.50 p. m.	18.0	15.2	9.1	30.04	0	0	------
1.20 p. m.	17.6	3.0	3.0	30.07	0	0	29.98
1.50 p. m.	17.0	15.2	3.0	29.74	6.1	9.1	29.85
2.20 p. m.	17.5	12.2	9.1	29.69	9.1	9.1	29.75
2.50 p. m.	17.5	21.3	18.3	29.63	6.1	9.1	29.61
3.20 p. m.	17.5	24.4	18.3	29.60	3.0	6.1	29.61
3.50 p. m.	17.5	------	------	29.43	9.1	3.0	29.52

[1] Time of low water, 5.47 a. m.; high water at 1.02 p. m. Range of tide, 2.7 feet.
[2] Observations at Stations I and III were made 5 and 10 minutes, respectively, after time shown in column 1.
[3] Velocity of current is shown in centimeters per second.

TABLE 5.—*Velocity of the current and salinity of water during ebb tide in Wareham River, September 22, 1926* [1]

Time [2]	Station II, channel				Station I	Station III	
	Current [3] Surface	Current [3] Bottom	Salinity, per mille Surface	Salinity, per mille Bottom	Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)
9.20 a. m.	------	------	------	------	------	3.0	30.18
9.50 a. m.	48.8	33.5	29.78	------	6.1	6.1	30.08
10.20 a. m.	54.9	33.5	29.81	30.12	12.2	12.2	30.01
10.50 a. m.	61.0	42.7	29.80	------	12.2	12.2	30.10
11.20 a. m.	61.0	42.7	29.70	------	15.2	12.2	29.96
11.50 a. m.	62.7	45.7	29.64	29.75	15.2	9.1	29.85
12.20 p. m.	62.7	45.7	29.63	------	15.2	9.1	29.75
12.50 p. m.	62.7	45.7	29.45	29.34	0	3.0	29.98
1.20 p. m.	42.7	30.5	29.36	29.36	0	------	29.81
1.50 p. m.	15.2	24.4	29.51	------	------	------	------
2.20 p. m.	21.3	27.4	29.45	------	------	------	------

[1] Time of high water, 7.42 a. m.; low water at 1.38 p. m. Range of tide, 5.3 feet.
[2] Observations at Stations I and III were made 5 and 10 minutes, respectively, after the time shown in column 1.
[3] Current velocity is shown in centimeters per second.

Hourly fluctuations in the salinity of water were studied on August 14 and 28, and September 22 and 28. The results of the observations presented in Tables 1, 2, 4, and 5, and Figure 9, show that the maximum salinity occurs at the time of high water and that the salinity decreases with the receding tide. It is noteworthy that at Station II (fig. 9) there was a marked drop in salinity approximately 2 hours after the time of high water, followed by an increase in salinity at the time of low water. Similar changes, but occurring one hour later, were noticed at Station VIII (Table 1), located half a mile south of Station II. The sudden drop in salinity during ebb tide, followed by its sharp increase, can be explained by the influx of brackish waters from Broad Marsh River (fig. 1) which at high tide are held in check by the heavier waters of Wareham River. As soon as the water in Wareham River during the receding tide reaches a certain level, the water from Broad Marsh River begins to flow, lowering the salinity at Stations II and VIII and temporarily impounding the saltier waters farther up the Wareham River. These conditions account for unusual fluctuations in salinities observed at Stations II and VIII. During the changes from low to high water, the salinity rises gradually, reaching the highest figure at the time of high water.

TIDES

The mean range of tide in Wareham River is 4.1 feet; the spring range of tide is 4.9 feet.

The velocity of the current in the channel and on the bars was measured with the Price electric current meter. The results are shown in Tables 4, and 5, and Figure 10.

The highest velocity, 62.7 centimeters per second, was observed at two-thirds ebb on September 22 (spring tide). At flood tide on September 28, the changes in the current velocities were rather irregular (fig. 10). As can be noticed from an examination of Figure 10, the maximum velocity of the tide occurred between the times of high and low water, and the time of slack water nearly coincided with them.

The strength of the current running over the bars and oyster beds is much less than in the channel, its maximum velocity not exceeding 12 centimeters per second.

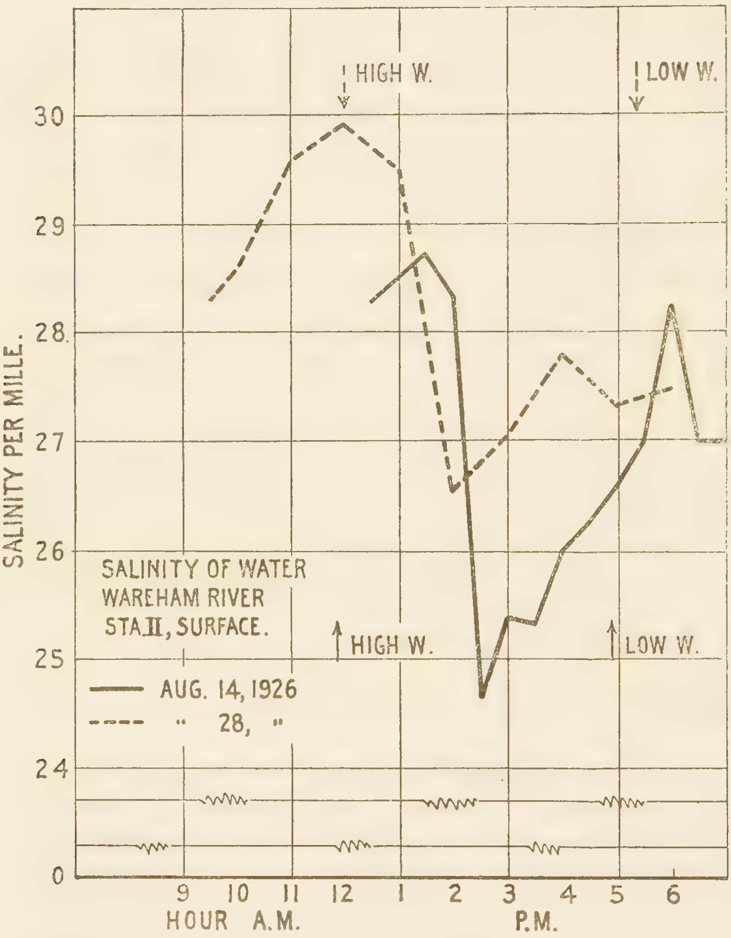

FIGURE 9.—Hourly fluctuations of surface salinity (per mille) during ebb tide, Station II, Wareham River, August 14 and 28, 1926

SPAWNING AND SETTING OF OYSTERS

Beginning July 9, plankton collections were made every other day at different stations by towing a plankton net made of No. 20 silk for 5 minutes; samples were preserved in formalin for further examination. The first occurrence of straight hinge oyster larvæ was recorded on July 21, and on the same day examination of oysters taken from the nearest bed showed that part of the oysters had spawned. Judging by the size, the larvæ were not over 2 days old; it can be concluded therefrom that spawning occurred on July 19 or 20, when the temperature of the water was about 23° C. The first spat (not over 1 day old) was noticed on the shells on August 6—15 days after the first appearance of the oyster larvæ in plankton. It is interesting to note that during July and August the oyster larvæ were very scarce in the plankton samples, although later on the setting in the harbor was heavy.

EXPERIMENTS WITH SPAT COLLECTORS

Crates filled with scallop and oyster shells were planted in three different localities in the river. On July 9, 24 crates containing oyster shells were placed at the north edge of the shell bed east of buoy S–20 (Station III) (fig. 4). On July 19, 13 crates filled with scallop shells were planted along the south side of Hamilton Beach, and 13 crates also containing scallop shells were planted at Swifts Beach. Scallop shells were used because no oyster shells were available at Wareham. The crates at Station III were planted 3 feet apart on the slope of the bar in four rows (figs. 11, 13) in such manner that the first row was always below low-water mark, the fourth row was entirely exposed at every low water, and the second and third rows occupied intermediate positions. One crate, placed on the top of the bar, was covered with water only at high tide. The difference between the levels corresponding to the top of the crate on the bar and the bottom of the crates in the first row was approximately 4 feet. Over the bar near which the crates were planted, scallop shells were scattered by the oystermen. The approximate dimension and shape of the area covered with scallop shells is shown in Figure 13. Because of the objection raised by the owner, who was afraid that planting of crates might affect setting on his bar, out of 24 crates only 1 was planted directly on the shelled area, the other 23 were set on the bottom where no planting was done. The crates were left undisturbed until the end of August, when they were examined and the number of spat in them counted. In order to make a comparison with the number of spat contained in the crates and on the bar, the latter was divided into 7 areas comprising 50 squares, from each of which a representative sample of shells was taken and the number of spat counted.

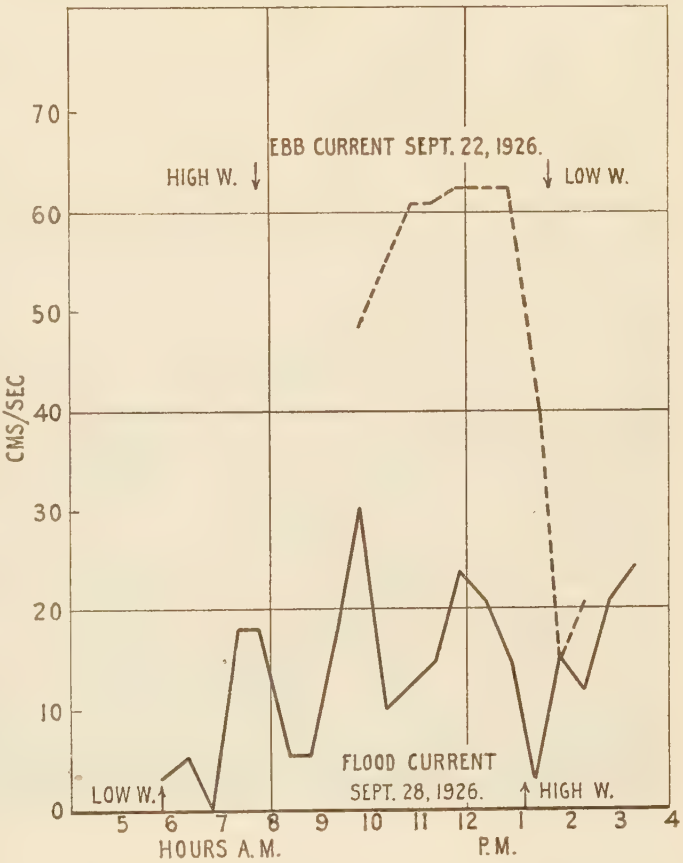

FIGURE 10.—Velocity of tidal currents in Wareham River, Station II, September, 1926

On the western side of the river, along Hamilton and Swifts Beaches (fig. 4), the crates were set between the tidal marks. During the period of 6 weeks that the crates were in the water, 11 of them were broken and carried out by the tide. All losses occurred in the crates planted on the western side of the river, where they were exposed to the action of waves. Those on the eastern side were well protected from heavy seas and sustained the test successfully.

Examination of the crates disclosed that scallop shells were not suitable for planting in the crates. In many of the crates a considerable portion of them was washed out, while those in the center were so ground up by the action of waves that they formed a solid mass of débris, which prevented the penetration of the larvæ. Much better results were obtained with oyster shells.

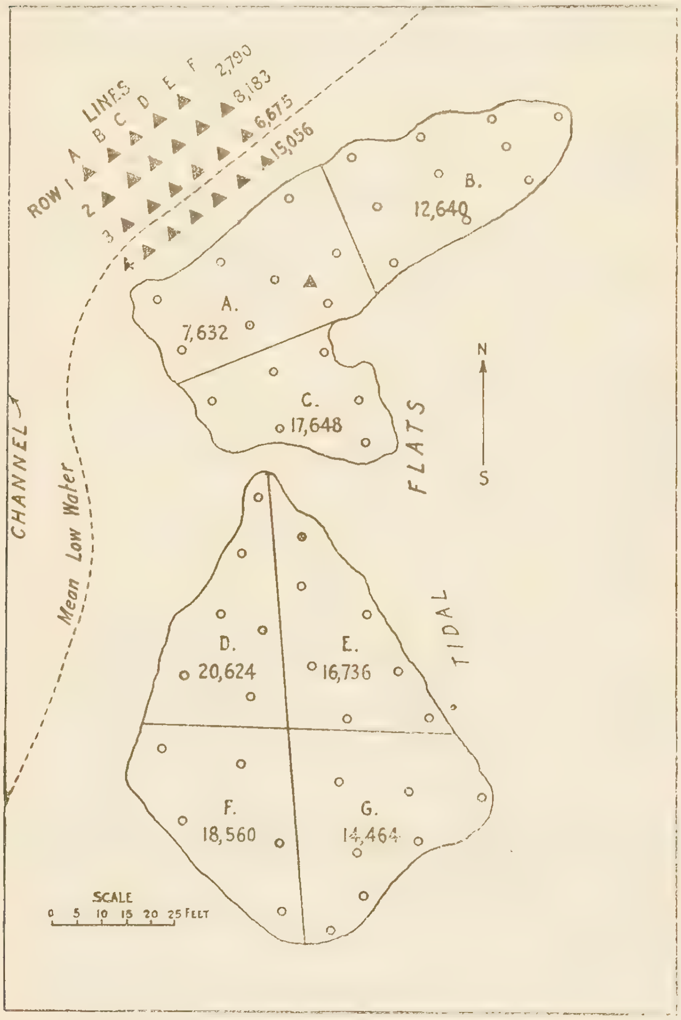

FIGURE 13.—Shelled beds and planted crates at Station III, Wareham River. Places from which samples of shells were taken are shown by o. Figures indicate average number of spat per bushel of shells. Location of crates is shown by triangles

When the counting of spat was begun on August 24, the spat had reached one-fourth of an inch in diameter and were easily noticeable on the surface of the shells.

The first problem to be studied was the distribution of spat within the crate. For this purpose the crate was divided into four horizontal zones or levels (fig. 14), and the abundance of spat in each zone was determined. In some of the crates a portion of the shells was washed out, and the remainder could be divided into three zones only. At every level shells touching lines *A*, *B*, and *C* (fig. 14, *A*) drawn from the center to each corner of the crate, were numbered from center outward and counts were made of the average number of spat per square inch of both shell surfaces. The results of the count of spat in one of the crates are presented in Table 6. The distribution of spat in various crates shows some variation, but it was noticeable that in all cases the concentration of spat at the top of the crate and in its corner was considerably greater than in its inner parts. From examination of shells taken from different portions of the crates, it was apparent that the oyster larvæ do not pene-

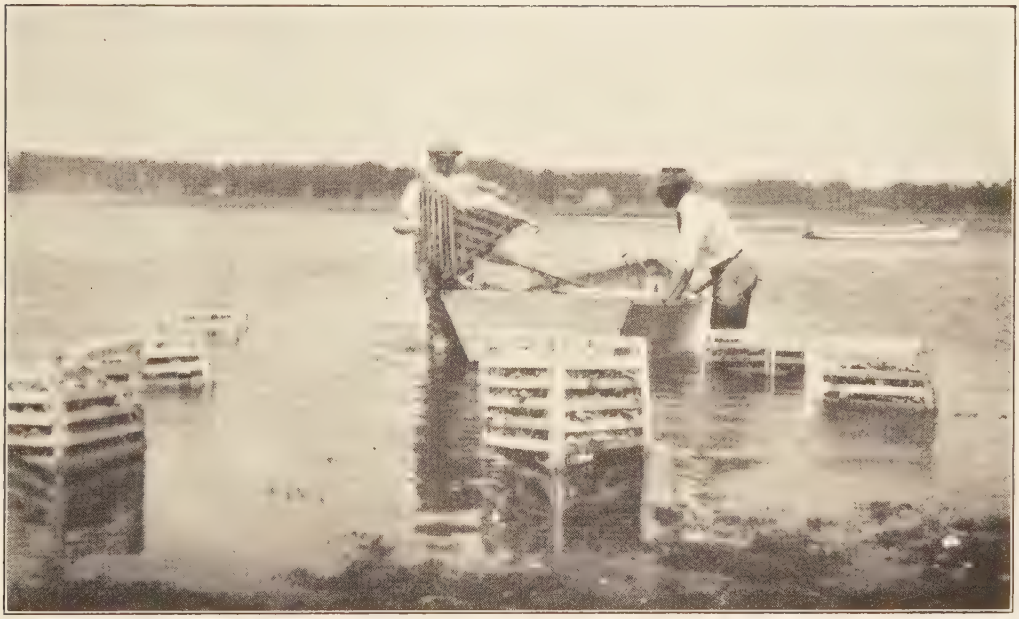

Figure 11.—Planting of crates in Wareham River

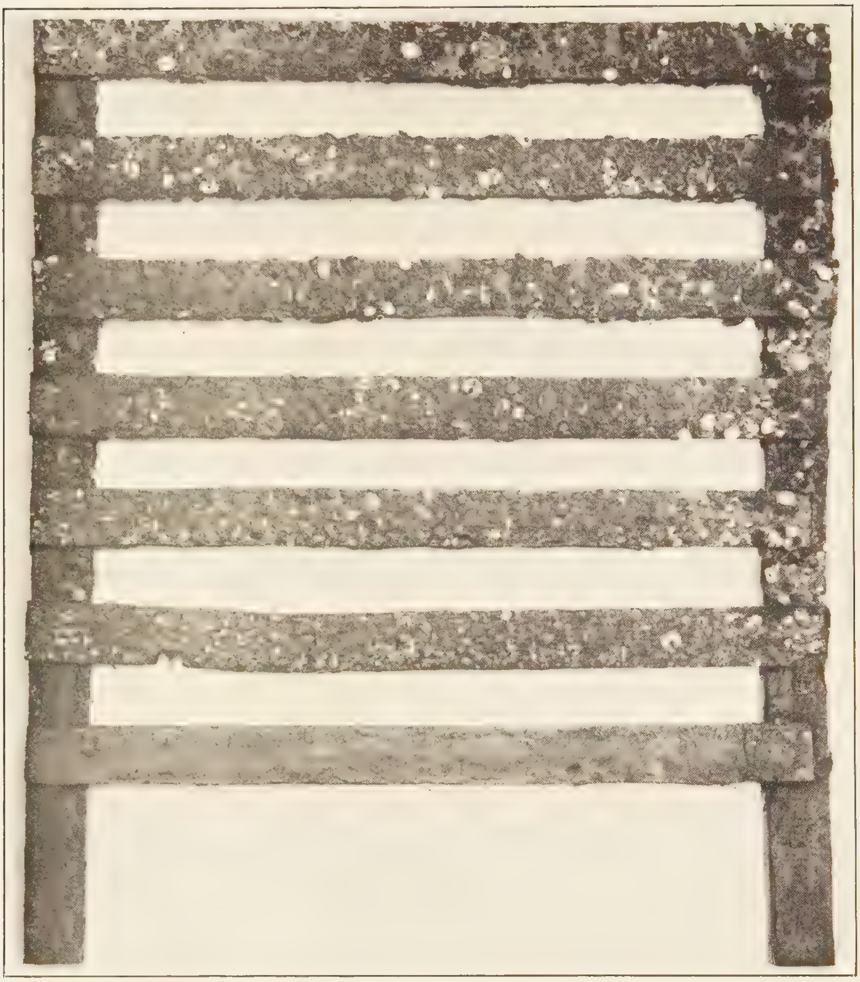

Figure 12.—Setting on the wall of a wooden crate, Wareham River

trate deeper than 6 inches from the surface and that the central portion of the crate had little value as a collector. This, however, can be easily improved by changing either the size or the shape of the crate. A more detailed analysis of the distribution of spat in the crate is given by Prytherch on pages 255 and 256.

TABLE 6.—*Distribution of spat within the crate* [1]

Shell No.	Level I			Level II			Level III			Level IV			Shell No.	Level I			Level II			Level III			Level IV		
	A	B	C	A	B	C	A	B	C	A	B	C		A	B	C	A	B	C	A	B	C	A	B	C
1	1	6	4	4	1	0	0	0	0	0	0	0	5	16	18	5	1	8	1	17	4	1	0	11	0
2	26	8	9	1	1	1	0	0	0	0	0	0	6	11	25	6	12	4	8	----	9	2	1	----	1
3	24	9	7	0	0	9	1	0	0	0	0	0	7	----	25	10	19	----	18	----	----	4	3	----	4
4	20	6	1	0	0	1	5	0	1	0	4	0													

---

[1] The figures indicate the average number of spat per square inch of both shell surfaces. (For meaning of letters *A*, *B*, and *C* and levels I to IV, see fig. 13.)

In order to determine the number of spat caught in the crates, they were emptied the shells well mixed, and a number of them were taken at random and thrown into a 2-quart container. Then the number of spat on all the shells of the sample was counted. The results of the counts are presented in Table 7.

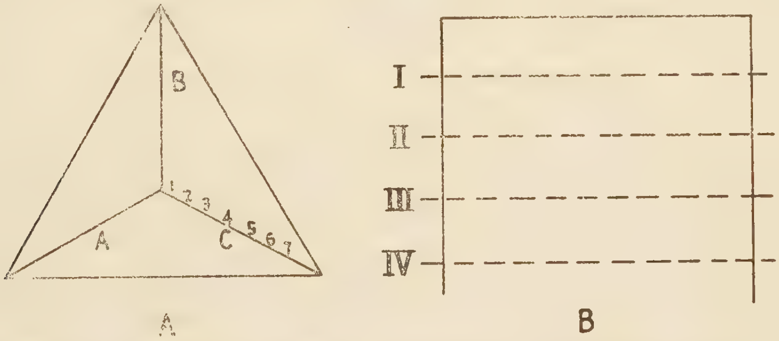

FIGURE 14.—Diagram showing the method of determination of the distribution of spat within the crate. *A*, Top view; *B*, side view

TABLE 7.—*Total and average numbers of spat caught in the crates*

Location	Number of crates	Total spat in crates	Average number of spat—	
			Per crate	Per bushel
Bar east of buoy S-2, Station II	24	436, 500	18, 188	9, 094
Hamilton Beach	6	230, 300	38, 383	19, 191
Swifts Beach	9	248, 100	27, 567	13, 784
Total	39	914, 900		
Average			23, 459	11, 729

All together in 39 crates there were obtained in round numbers 915,000 seed oysters. On the average there were 23,459 seed oysters per crate, or 11,729 per bushel.

Inasmuch as the crates were set in different localities and at different depths, and as some of them were filled with oyster while others were filled with scallop shells, it is of interest to analyze the results of the experiment in a more detailed manner.

We begin our discussion with the crates planted in front of Hamilton and Swifts Beaches. Thirteen crates were planted at each locality between the tidal marks. All the crates were partially exposed at low water and were set about 10 feet apart. A number of them were destroyed during the summer; only 6 crates remaining at Hamilton Beach and 9 at Swifts Beach. The wood of the crates was badly damaged by the shipworm and hardly was able to sustain the weight of the shells. The difference in the average number of spat per crate obtained in each locality was insignificant, 38,383 at Hamilton Beach and 27,557 at Swifts Beach; the variations in the number of spat in different crates (Table 8) were, however, very large.

TABLE 8.—*Number of spat caught in the crates*

Crate number	Spat per crate	Crate number	Spat per crate
HAMILTON BEACH		SWIFTS BEACH	
25	94, 000	31	20, 700
26	56, 800	32	28, 300
27	10, 000	33	30, 800
28	2, 200	34	25, 300
29	3, 800	35	11, 700
30	65, 000	36	11, 500
		37	21, 800
Total	230, 000	38	87, 500
Average per crate	38, 383	39	10, 500
		Total	248, 100
		Average per crate	27, 567

The low figures in crates 27, 28, 29, 35, 36, and 39 were due to the fact that a considerable number of shells were washed out from these crates and the remainder represented what, at the time of setting, constituted the central portion of the crate.

The crates planted at Station II were less attacked by the shipworms, and none of them was lost during the season. They were filled with oyster shells, which, owing to the action of the waves, became by the end of the season more tightly packed, but none of which was either washed out or ground up, as happened with the scallop shells. On August 31 a representative sample of shells was taken from each crate and the number of spat was counted. The results of counting are given in Table 9.

The highest average intensity of setting, amounting to 30,117 spat per crate, was found in row 4, which was entirely exposed at low water; the lowest setting, averaging 5,580 per crate, took place in row 1, which was at all times submerged; while in rows 2 and 3 the setting averaged 16,366 and 13,350 per crate respectively. Counting the averages for every group of four crates in the lines *A* to *E*, we find no significant variations in the number of spat. This shows very conclusively that the zone of the most intensive setting was above the low-water mark. The maximum number of spat (50,100) was found in the crate set on the top of the bar above all other crates. (Fig. 13.)

TABLE 9.—*Spat caught in the crates planted at Station III, Wareham River. (See fig. 13.)*

Row No.	Line A	Line B	Line C	Line D	Line E	Line F	Average—	
							Per crate	Per bushel
1	14, 100	2, 300	5, 200	1, 900	3, 900	----------	5, 580	2, 790
2	21, 800	8, 200	5, 000	20, 100	15, 700	26, 800	16, 366	8, 183
3	16, 100	9, 100	17, 400	6, 300	15, 700	15, 500	13, 350	6, 675
4	16, 700	48, 500	18, 000	47, 100	24, 000	26, 400	30, 117	15, 058
Average per crate	17, 175	17, 025	11, 850	18, 850	14, 825	22, 900	----------	----------

It is interesting to compare the setting in the crates with the setting on the shells (beds *A* and *B*, fig. 13). The beds are separated by only a few feet; they were mapped and divided into 7 areas comprising 50 squares, from which samples of shells were taken. The number of spat on the bed was determined by counting them on both surfaces of 10 shells taken at random from the top layer and from 10 shells at a deeper layer of the bed. It was noticed that there were many more spat on the upper layer of cultch than there was in its deeper layer. This can be seen in Table 10.

TABLE 10.—*Number of spat in top layer and in deeper layers of shells on shell beds*

Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell	
	Top layer	Deeper layer		Top layer	Deeper layer		Top layer	Deeper layer		Top layer	Deeper layer
Shell No. 1	13	0	Shell No. 4	4	2	Shell No. 7	3	0	Shell No. 10	14	1
Shell No. 2	12	1	Shell No. 5	12	0	Shell No. 8	8	0			
Shell No. 3	9	1	Shell No. 6	9	3	Shell No. 9	8	0			

In order to facilitate comparison, all the squares from which samples were taken were grouped in 7 large sections (fig. 13, *A–G*), and the average number of spat per bushel of shells was computed for each section separately. The intensity of setting over the beds varied from 7,632 spat per bushel in section *A*, located close to the fourth row of crates, to 20,624 in section *D*. The average intensity for both beds was 15,472 seed per bushel, approximately the same as that obtained in the fourth row of crates (15,058 per bushel). It should be borne in mind that oyster shells were planted in the crates, while scallop shells were scattered over the beds. The number of scallop shells per bushel is about 2½ times that of oyster shells; hence, because of the greater surface area exposed for the attachment of larvæ, the setting should be heavier on the former than on the latter. For practical purposes there is no advantage, however, in increasing the intensity of setting. In the case of oyster shells, a uniform set amounting to 3,000 spats per bushel can be regarded as an acceptable minimum. For fragile scallop or jingle shells, the figure should be higher.

The problem consists in increasing the productivity of seed oysters without increasing the intensity of setting. The comparison of setting in the crates with that on the bed should refer, therefore, not to the volumes of shells used, but to the unit of area over which shells or crates are planted. Each crate covers an area of 2 square feet, and a comparison of the number of spat found over this area on the bed with the number of spat in the crates gives us a true idea of the efficiency of the crate method. In order to make such a comparison, it is necessary to know the number of scallop shells planted over a unit area of the bed. It was found that on the average there were 86 scallop shells on each square foot of the bed and that 318 scallop shells formed one peck. Taking these figures as representative of the size of shells and the density of planting in Wareham River, we find that there were 0.27 pecks of shells planted on each square foot of the bed, or 0.54 pecks on each 2 square feet. Calculated on this basis, the number of spat per unit of 2 square feet in different sections of the bed is given in Table 11.

TABLE 11.—*Number of spat per bushel and per unit of area on shelled bed, Wareham River, Mass.*

Section	Spat per bushel	Spat in each 2 square feet
A	7,632	1,030
B	12,640	1,706
C	17,648	2,382
D	20,624	2,784
E	16,736	2,259
F	18,560	2,506
G	14,464	1,953
Average	15,472	2,089

As has been shown above, the average setting in the crates of the fourth row, which was nearest to the bed, was 30,000 over 2 square feet, or about fifteen times greater than the average setting over the whole bed. If we compare the setting in the fourth row of crates with the setting in the nearest section A of the shelled bed, we find that seed production in the crates was nearly thirty times greater than that of the adjacent portion of the bed.

It is apparent from the results of the present experiment that the production of seed oysters over a given area of bottom can be greatly increased by the planting of shells in crates, thus utilizing three dimensions of the setting zone instead of only two. Furthermore, the setting area can be considerably enlarged by planting the crates on sand bars or soft mud flats, where ordinary scattering of shells is impossible. If necessary, the legs of the crates can be made longer to prevent their sinking into the soft bottom. As has been shown by the present experiments, the most intensive setting in Wareham River took place about 2 feet above the highest point on the bar where shells were planted. It is obvious that many more seed oysters could be obtained by planting cultch at this particular level. One would expect that more intensive planting might reduce the concentration of spat on shells, but as had already been mentioned, a great intensity of setting is not wanted, and for practical purposes 3,000 spat per bushel uniformly distributed can be regarded as a fair commercial set. For the successful growth of oysters, uniformity in distribution is of far greater importance than intensity of setting.

It has been shown that some of the crates were badly damaged by the shipworm and other wood-boring organisms and that the crates can be protected by dipping them into a solution made of 2 parts of lime and 1 part of cement. In 1928 several crates coated with this mixture were planted at the mouth of Crooked River near Wareham. They were not attacked by the boring organisms and sustained the experiments very well. It is interesting to note that wooden lath coated with a mixture of lime and cement affords a wonderful surface for the attachment of oysters. (Fig. 12.) In one of the crates the number of spat attached to the lath was counted by determining the number of spat over 1 square inch at 60 different places taken at random on the sides and bottom of the crate. The number of spat varied from 0 to 50 to a square inch, averaging 14.2. As the outside and inside surfaces of the crate have a total area of 1,730 square inches, the estimated number of seed oysters attached to this crate was 24,566. In determining the area of the crate, the surface of the edges of the lath, which was ¼-inch thick and was covered with seed oysters, was not taken into consideration. The market value of seed oysters which could be easily detached from the coated surface of the crate would pay completely for the cost of the crate, shell, and labor.

Experiments carried out in Wareham River proved hat the crate method has many advantages over ordinary planting, and that it particularly suitable for localities where setting is regular and where the production of seed osyters is the main business of the industry.

III. OBSERVATIONS AND EXPERIMENTS IN SEED-OYSTER COLLECTION IN ONSET BAY, MASS., 1927, 1928

By PAUL S. GALTSOFF and H. C. McMILLIN

BRIEF DESCRIPTION OF THE LOCALITY

Onset Bay is a small indentation of the northern end of Buzzards Bay, about 2 miles west of the entrance to the Cape Cod Canal. (Fig. 15.) The bay is about 2½ miles long, not over half a mile wide, and has two islands—Onset Island at the entrance to the bay and Wicket Island in the middle of it. Numerous sand bars obstruct navigation in the bay. Outside of a dredged channel the depth of the water is from 1 to 17 feet at low tide. The shore line is very irregular, forming several points and coves. The bottom of the bay is generally hard and covered with a profic growth of eel grass. A small amount of fresh water enters the bay through several mall creeks draining the surrounding low and marshy land.

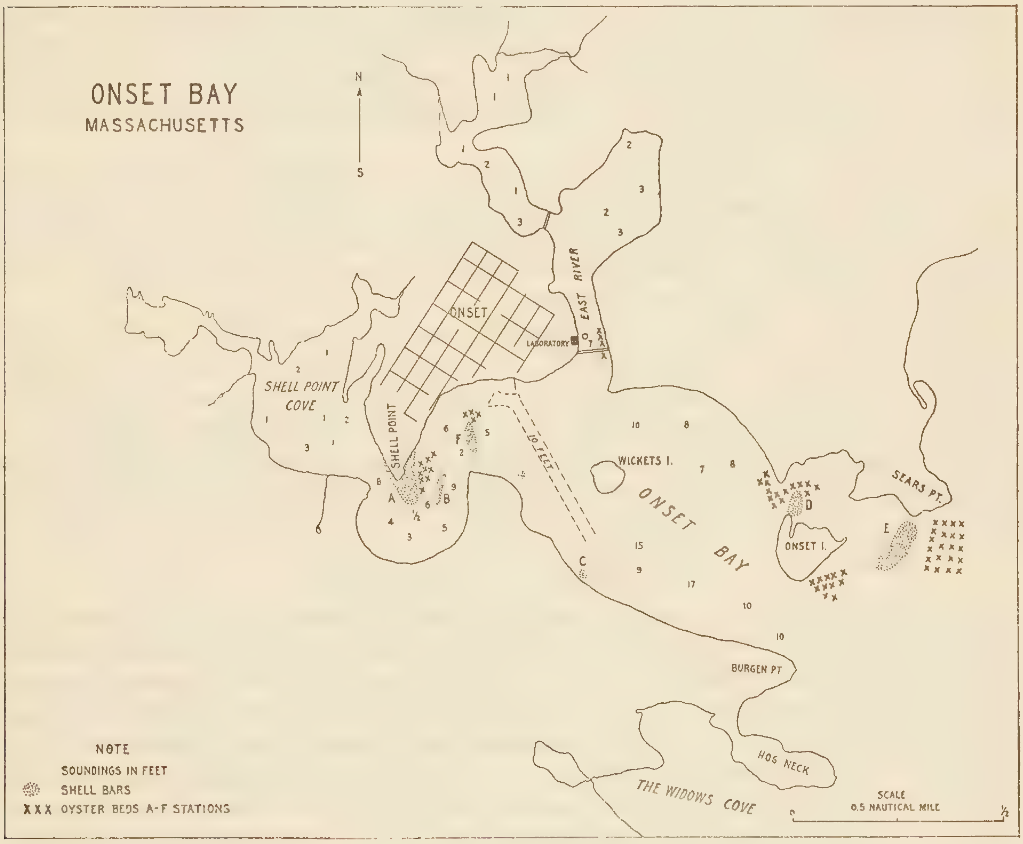
ONSET BAY
MASSACHUSETTS
N
S
EAST RIVER
ONSET
LABORATORY
SHELL POINT COVE
SHELL POINT
10 FEET
WICKETS I.
ONSET BAY
ONSET I.
SEARS PT.
BURGEN PT
HOG NECK
THE WIDOWS COVE
A
B
C
D
E
F
NOTE
SOUNDINGS IN FEET
SHELL BARS
XXX OYSTER BEDS A-F STATIONS
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 15.—Onset Bay, Mass.

At present there are no natural oyster bottoms in Onset Bay. Adult oysters and 3 years old are brought in every year from Long Island Sound, Delaware, and other places and planted here on hard and gravelly bottoms a few feet below low water. The general distribution of the beds is shown in Figure 15. According to local oystermen, there are only 12 acres in the bay that are considered good growing grounds and capable of supporting the growth of 500 bushels of oysters to each acre. The adult oyster population in the bay is changeable and varies depending on the commercial operations of the industry. Hence, it was impossible to ascertain accurately the number of oysters present at the beginning of the spawning season; it was estimated, however, that in July, 1928, there were at least 15,000 bushels of adult oysters in various sections of the bay.

The principal business of oystermen in Onset Bay is seed production, only a few native oysters being grown locally, as nearly all the crops of seed oysters is sold the first fall, before the onset of cold weather, which would kill the spat above the tide lines. The area devoted to catching of spat is rather small; it comprises 7 bars having a total area of about 8½ acres confined to the tidal land entirely exposed at low water. About 2,000 bushels of scallop, quahaug, or oyster shells are usually planted to each acre of bar.

Onset Bay has a well-established reputation as an excellent seed-producing area, where setting is usually very good. On the other hand, the area utilized for the production of seed is very small and the possibility of extending it has great importance to the local industry. These facts were the main reasons for selecting the place for the experiments with spat collectors.

The work in Onset was carried out during the summers of 1927 and 1928. Through the courtesy of the Schroeder & Besse Oyster Co., a space in the office building of the company was given for a temporary laboratory, and valuable assistance was rendered in supplying boats and equipment and in giving practical information concerning the oyster industry of the region. Under the general direction of P. S. Galtsoff, field observations were carried out in 1927 by Dr. E. B. Perkins and in 1928 by H. C. McMillin.

TEMPERATURE OF THE WATER

Temperature readings were taken daily at various stages of the tide at station A, off Shell Point (fig. 15), which was selected because Shell Point bar is the most important seed-producing area of the bay. On account of the shallowness of the place, only surface temperature was recorded. The results of the observations made in July–September, 1927 and 1928, presented in Figure 16 and Tables 12 and 13 show that except for five days in August, 1927, the temperature of the water during the 2-month period (July–August) was above 20° C., and that in both years the maximum temperature, 26.5° C. in 1927 and 26.1° C. in 1928, occurred in the second half of July.

An attempt to obtain a continuous record of the temperature of the water was made in 1928 when a thermograph was installed on a float anchored in East River just above the bridge. (Fig. 15.) Unfortunately on July 14 the thermograph was lost in a gale which swept Cape Cod and produced strong waves even in a well protected harbor. The thermograph records obtained for 13 days from June 29 until July 13, show that during this period the maximum fluctuation of the temperature within each 24-hour period was 4°.

TABLE 12.—*Temperature and salinity of the water at the surface of Onset Bay near Shell Point, July–September, 1927*

[Observations were made between 10 a. m. and 5.30 p. m.]

Day of the month	July		August		September		Day of the month	July		August		September	
	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille		Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille
1	20. 5	28. 28	23. 3	27. 11	20. 0	------	17	22. 8	28. 40	21. 7	26. 58	------	------
2	20. 8	27. 75	23. 3	27. 05	21. 1	26. 31	18	22. 8	29. 27	20. 5	26. 42	------	------
3	21. 7	28. 55	23. 3	26. 38	21. 7	27. 00	19	21. 1	27. 83	18. 9	26. 44	------	------
4	21. 1	28. 03	24. 4	26. 00	22. 2	------	20	21. 1	28. 55	18. 3	29. 65	------	------
5	21. 1	28. 35	24. 4	26. 58	22. 2	------	21	21. 7	27. 83	18. 3	26. 49	------	------
6	21. 7	27. 63	24. 2	26. 62	22. 8	26. 26	22	21. 4	28. 03	19. 4	26. 11	------	------
7	20. 5	29. 87	25. 0	26. 02	22. 5	25. 30	23	21. 4	28. 82	21. 1	26. 56	------	------
8	21. 1	28. 55	23. 9	26. 02	22. 2	24. 44	24	22. 2	26. 35	21. 7	27. 16	------	------
9	21. 1	27. 43	23. 9	26. 56	22. 2	------	25	22. 5	28. 13	20. 5	25. 01	------	------
10	21. 1	26. 91	23. 3	26. 06	------	------	26	24. 7	28. 28	21. 1	27. 27	------	------
11	22. 2	27. 39	23. 9	26. 82	------	------	27	23. 3	27. 86	20. 8	26. 18	------	------
12	21. 7	27. 01	24. 4	26. 62	------	------	28	23. 3	27. 88	20. 5	------	------	------
13	22. 2	27. 86	24. 2	25. 30	------	------	29	26. 5	27. 57	20. 5	------	------	------
14	23. 9	28. 17	------	26. 82	------	------	30	26. 2	27. 25	19. 4	24. 99	------	------
15	------	28. 62	22. 2	26. 67	------	------	31	23. 3	27. 94	20. 3	26. 38	------	------
16	23. 3	29. 22	22. 3	25. 90	------	------							

TABLE 13.—*Temperature and salinity of the water at the surface of Onset Bay, near Shell Point, July–August, 1928*

Date	Time	Temperature, ° C.	Salinity, per mille	Date	Time	Temperature- ° C.	Salinity, per mille	Date	Time	Temperature, ° C.	Salinity, per mille
July 2	1.45 p. m.	24.4	27.36	July 17	10.11 a. m.	24.1	28.03	July 30	3.10 p. m.	23.9	28.01
3	11 a. m.	25.0	27.64	18	1.45 p. m.	26.1	27.84	31	11.07 a. m.	23.7	27.99
5	12.05 p. m.	24.0	28.24	19	10.40 a. m.	25.1	28.16	Aug. 2	9.55 a. m.	22.9	28.31
6	1.51 p. m.	21.3	27.77	20	12.03 p. m.	24.6	28.16	3	10.05 a. m.	24.1	28.45
7	3.06 p. m.	20.4	28.30	21	8 a. m.	21.8	28.16	6	10.46 a. m.	23.1	28.77
9	10.46 a. m.	22.7	28.51	23	9.50 a. m.	21.7	27.70	9	2.43 p. m.	23.9	28.73
10	8.50 a. m.	22.8	27.97	24	8.20 a. m.	22.0	27.21	10	9.55 a. m.	24.3	28.73
12	5 p. m.	23.1	29.17	25	9.16 a. m.	26.1	27.17	13	11.35 a. m.	24.5	29.11
13	9.45 a. m.	22.3	27.84	26	7.19 a. m.	21.9	27.72	20	8.45 a. m.	24.4	29.85
16	10.15 a. m.	23.4	26.83	27	8.15 a. m.	22.9	27.72	31	3.07 p. m.	25.7	29.66

A study of the horizontal distribution of the temperature of the water was made in 1928 with the view of determining whether there were any significant differences in the temperature at different sections of the bay. Observations were carried out on calm and warm days of June 17 and 26, August 20, and September 4. Twenty-nine stations were distributed uniformly over the whole area from the head of the bay to its mouth, and surface temperature readings were taken within less than 90 minutes. On June 17 observations were made at half flood; on June 26 records were taken both at low and high water; on August 20 at high water; and on September 4 at low water. The results of these observations, presented in Table 14, show no significant differences in the temperatures of the water in various sections of the bay. It can be noticed that on June 26 the temperature of the water in the lower section of the bay (stations 25–29) was less than 1° cooler than it its upper part. On August 20 the lowest temperature (23.7° C.) was observed in the middle of the bay (station 13) and the highest (25.6° C.) close to the sand flats (station 22); the temperature in the upper part of the bay (station 1) was 25° C. On September 4, observations made at low tide early in the morning (between 4.40 a. m. and 5.54 a. m.) show that the temperature of the water in the upper part of the bay (station 2) was 1.2° C. less than in the middle part.

The nearly uniform horizontal distribution of the temperature and the fact that there is but slight change in the temperature of the water during one complete tidal cycle (June 26) indicate that the comparatively cool water of Buzzards Bay, which enters Onset Bay with the flood tide, warms up when passing through the shallow channels at the entrance of the bay and by coming in contact with the exposed and warm tidal flats.

TABLE 14.—*Horizontal distribution of temperature and salinity at the surface of Onset Bay, summer 1928*

UPPER SECTION

Station number	June 17, 1928			June 26, 1928						Aug. 20, 1928			Sept. 4, 1928		
	High water at 7.00 a. m.			Low water at 7.51 a. m.			High water at 3.16 p. m.			High water at 10.05 a. m.			Low water at 3.53 a. m.		
	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille
	a. m.			*a. m.*			*p. m.*			*a. m.*			*a. m.*		
1	8.37	19.3	28.60	8.27	19.2	27.05	3.31	19.7	28.84	11.56	25.0	29.72	5.51	------	27.64
2	8.41	19.5	28.21	------	------	26.98	3.28	19.8	28.48	11.54	24.9	29.79	5.52	20.8	26.97
3	8.45	19.7	27.92	------	------	27.57	3.25	19.8	28.41	11.53	25.0	29.66	5.49	------	27.23
4	8.49	19.0	27.65	------	------	27.78	------	------	------	------	------	29.66	5.47	------	27.77
5	8.52	19.3	28.19	------	------	28.13	3.17	19.6	29.13	------	------	29.72	5.45	------	28.78
6	8.57	19.6	28.31	------	------	28.33	------	------	28.78	11.44	24.6	29.05	5.49	------	28.39
7	9.00	19.1	28.71	------	------	28.73	------	------	28.93	------	------	29.72	5.40	21.1	28.78
8	9.04	19.4	29.58	8.53	19.0	28.66	3.09	19.4	29.05	------	------	30.05	5.39	------	28.31
9	9.08	19.1	29.33	------	------	28.73	------	------	29.13	11.36	24.8	29.85	5.37	------	28.26
MIDDLE SECTION															
10	9.12	19.2	29.27	------	------	28.86	------	------	29.13	11.34	24.4	29.92	5.34	------	28.65
11	9.14	19.3	29.40	------	------	28.89	3.00	19.0	29.38	------	------	30.12	5.30	------	27.50
12	9.25	19.0	29.38	9.00	19.0	28.13	2.55	19.2	28.98	------	------	30.12	5.28	------	27.17
13	9.35	18.8	29.67	------	------	28.59	------	------	29.23	11.25	24.3	30.12	5.27	------	27.70
14	9.38	18.9	29.98	------	------	29.13	2.52	------	30.71	------	------	30.05	5.25	22.0	27.14
15	9.41	18.8	29.85	------	------	28.60	2.50	19.2	29.45	11.22	------	30.32	5.22	------	28.85
16	9.45	19.0	29.52	------	------	28.46	2.48	19.4	29.58	------	------	30.12	5.20	------	29.02
17	9.47	19.0	29.17	------	------	28.21	2.44	------	29.09	------	------	30.12	5.18	------	28.45
18	------	------	------	------	------	28.66	2.41	19.4	29.45	11.15	23.7	30.12	5.17	------	29.11
19	------	------	------	9.22	18.8	28.79	2.39	------	29.65	------	------	30.18	5.12	------	28.85
20	------	------	------	------	------	29.10	------	------	29.98	11.10	23.4	30.44	5.10	21.1	29.38
21	------	------	------	9.27	18.6	29.20	------	------	29.93	11.07	------	30.18	5.08	------	30.01
22	------	------	------	9.30	18.5	29.33	------	------	29.92	11.03	25.6	30.25	5.05	------	29.01
23	------	------	------	9.42	18.6	29.33	2.27	------	30.05	11.00	24.6	30.25	5.03	21.2	29.40
24	------	------	------	------	------	29.72	2.24	19.5	29.85	10.37	24.2	30.18	4.53	------	29.33
LOWER SECTION															
25	------	------	------	------	------	29.99	------	------	30.05	------	------	30.44	4.50	------	29.88
26	------	------	------	------	------	30.13	------	------	30.13	10.52	------	30.70	4.46	21.3	29.88
27	------	------	------	------	------	30.19	------	------	30.12	10.43	------	30.44	4.44	------	29.72
28	------	------	------	10.04	18.5	30.07	------	------	30.12	------	------	30.44	4.43	------	29.46
29	------	------	------	10.07	18.4	30.07	2.14	18.9	30.12	10.57	24.2	30.50	4.40	------	30.05

SALINITY

Daily observations of salinity made in the summers of 1927 and 1928 (fig. 16) by means of hydrometer readings show that during the first summer the concentration of salts varied from 24.99 to 29.07 per mille; during the second summer, the fluctuations were from 27.65 to 29.85. By examining Figure 16 one can see that the lower salinities of the summer of 1927 were apparently due to the higher precipitation during that year.

A study of the horizontal distribution of salinities was made in 1928 on the days when the distribution of the temperature was studied. It is clear from the examination of Table 14 and Figure 17 that the salinity increases from 27.05–29.72 at the head of the bay to 30.05–30.50 at its entrance. At low tide the differences in the salinities at the head of the bay and at its entrance were 3.02 per mille on July 26

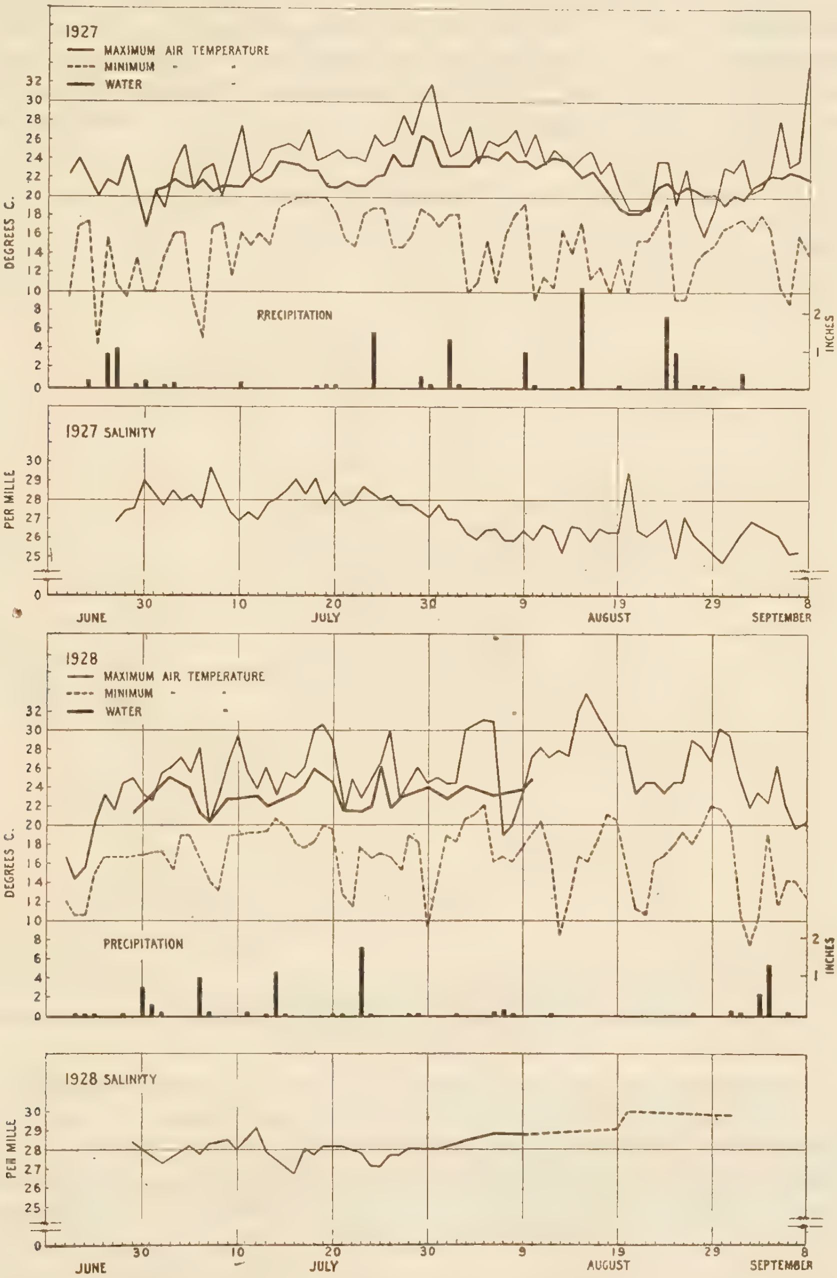

FIGURE 16.—Maximum and minimum air temperature, precipitation, water temperature, and salinity (per mille) in June and September, 1927 and 1928. Onset Bay, Mass.

and 2.41 per mille on September 4. At high water the salinity throughout the bay was higher, the difference between the head of the bay and its lower section being only 1.28 (June 26) and 0.78 (September 4).

TIDES

The mean range of tide in Onset Harbor is 4.1 feet and the spring range is 4.9 feet. The observations of the rise and fall of the tide were made on the tidal gage set up at the end of Shell Point. One of the points of interest in a study of tidal phenomena is the determination of the time of slack water in relation to the stage of tide. It has been shown by Prytherch (1929) that oyster larvæ in Milford Harbor were most abundant during the low slack water periods when the current velocities were from 0 to 18.3 centimeters (0.6 foot) per second, and that they ceased swimming when the current velocity exceeded this figure. Hence, the determination of the exact time of slack water and of its duration in relation to the stage of tide may have some bearing on the understanding of the factors which cause the aggregation of the larvæ during the setting period in a definite zone. The determination of the time of high slack water was made on a very calm day, August 3, 1928, when the rise of the water and surface tidal currents were observed at very brief intervals by watching the tidal gage and noticing the movement of small floats thrown on the surface of the water.

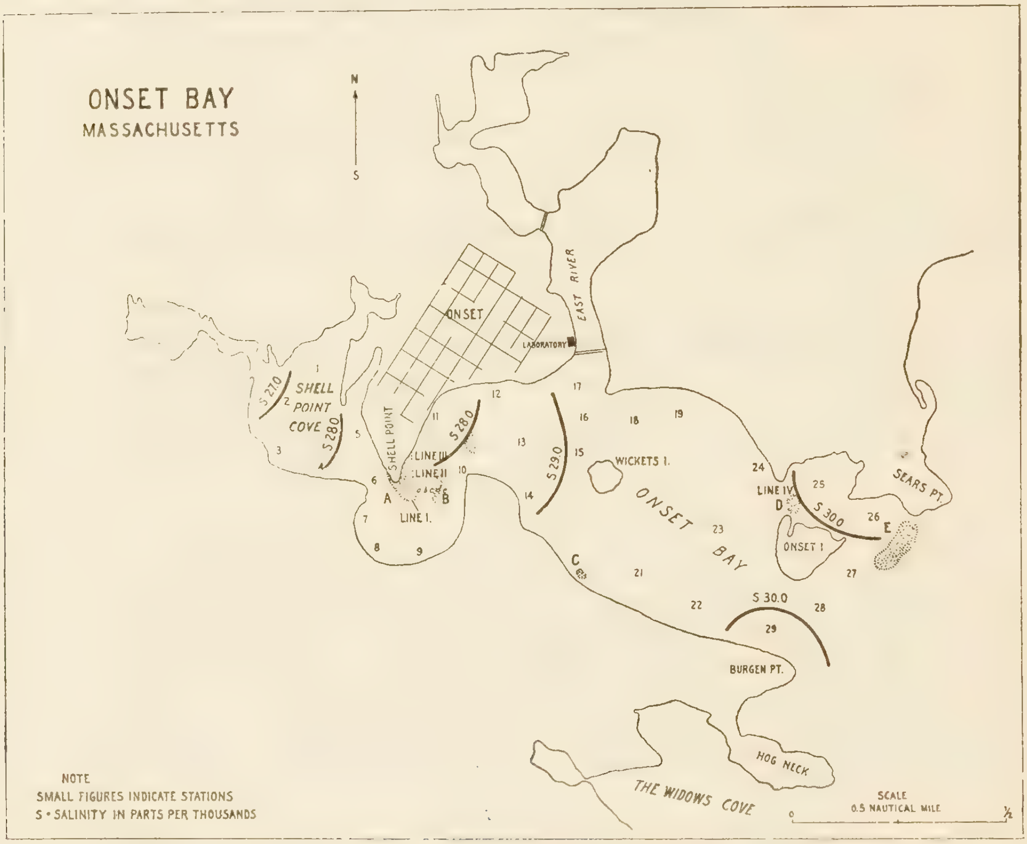
ONSET BAY
MASSACHUSETTS
N
S
ONSET
EAST RIVER
LABORATORY
SHELL POINT COVE
SHELL POINT
S 27.0
S 28.0
S 28.0
S 29.0
S 30.0
S 30.0
LINE I.
LINE II
LINE III
LINE IV
A
B
C
D
E
WICKETS I.
ONSET BAY
ONSET I.
SEARS PT.
BURGEN PT.
HOG NECK
THE WIDOWS COVE
1
2
3
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
21
22
23
24
25
26
27
28
29
NOTE
SMALL FIGURES INDICATE STATIONS
S = SALINITY IN PARTS PER THOUSANDS
SCALE
0.5 NAUTICAL MILE
0
½

FIGURE 17.—Horizontal distribution of salinity in Onset Bay, September 4, 1928, at low water. Small figures indicate stations; large figures indicate salinities (per mille)

Table 15.—*Observations of the height of the tide and the time of slack water, Onset Bay near Shell Point, August 3, 1928*

Time	Height of tide	Current	Time	Height of tide	Current	Time	Height of tide	Current	Time	Height of tide	Current
a. m.	′ ″		*a. m.*	′ ″		*a. m.*	′ ″		*a. m.*	′ ″	
8.03	4 4.7	Flood.	8.43	4 7.3	Slack water.	8.54	4 7.5	Ebb.	9.55	4 3.7	Ebb.
8.15	4 5.4	Do.	8.49	4 7.6	Do.	9.30	4 4.2	Do.	10.15	4 0.2	Do.
8.30	4 7.2	Do.	8.50	4 7.6	Ebb.	9.45	4 4	Do.			

It can be noticed from the examination of Table 15 that the maximum height of tide occurred 6 minutes after the slack water and that the period when there were no surface currents lasted only 7 minutes. On account of slow currents which can not be recorded with the current meter, such observations are possible only on very calm days. It is unfortunate that weather conditions did not permit repeating them several times and determining the time of slack water at low tide; the latter, however, is of less significance, because the zone of the heaviest setting in Onset Harbor is above low-water mark.

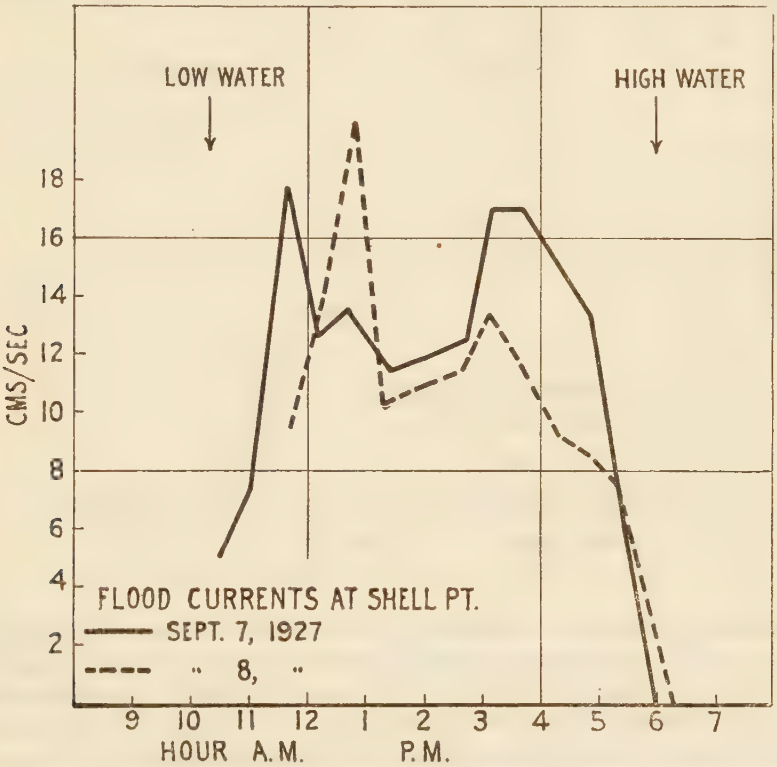

Figure 18.—Surface flood currents in the channel at Shell Point, September 7 and 8, 1927

The velocity of tidal current in any inshore body of water is determined by two factors: The volume of water that flows through the channel past a given point, and the cross sectional area at this point. In a shallow bay like Onset Bay with an irregular shore line and numerous bars obstructing the free passage of water, the tidal movements do not conform with the comparatively simple motion that takes place in an unobstructed channel or in a wide, deep river. On account of changes in the cross sectional areas due to the slope of the bar the irregularity in the horizontal movements of water flowing over the bar is more pronounced than it is in the channel.

Current-meter readings were made on calm days when there was only slight interference caused by the wind. The results of the observations are presented in Figures 18, 19, 20. It is obvious from an examination of Figures 18 and 19 that the periods of slack water in the channel near Shell Point occur about the times of the tide, and that the strength of the tide comes between the times of high and low water. In this respect tidal conditions at Onset Harbor, like those of Long Island Sound, present the characteristics of stationary wave motion. An interesting feature of the tidal currents at Shell Point is the appearance of two velocity peaks during the flood tide, which are probably due to a temporary piling up of water in a narrow entrance at Shell Point (see fig. 15) and blocking the horizontal movement of water on the bar. The maximum velocity (20 centimeters per second) was observed during flood tide. As can be noticed from Figures 18 and 19, flood-tide currents in Onset Harbor are stronger than ebb currents, and the changes in the velocities during the receding tide are more gradual than they are during the flood tide.

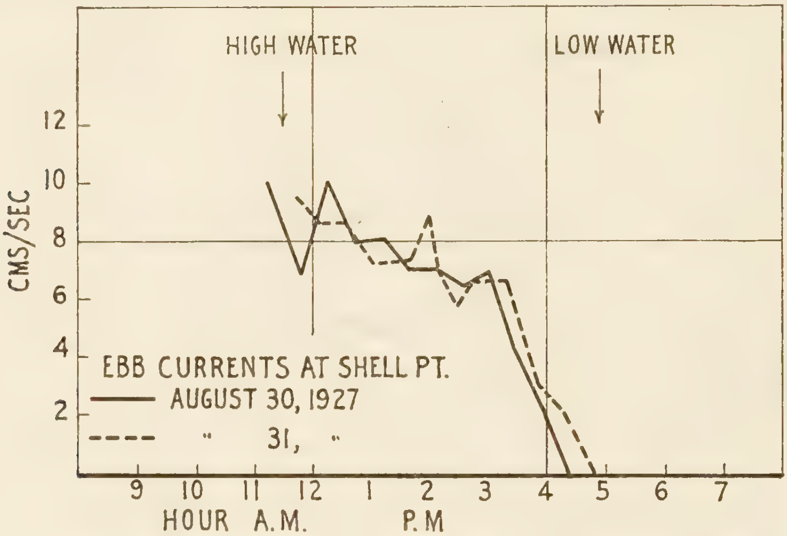

FIGURE 19.—Surface ebb currents in the channel at Shell Point, August 30 and 31, 1927

From a biological point of view, it is of interest to determine the current velocities on the bar which is exposed at low water and where, as had been determined by previous observations, the setting of oysters is usually good. Because of the gravelly bottom over the bar, the receding tides leave no pools of water; hence the oyster larvæ that set on the bar are undoubtedly brought in with the incoming or outgoing tide. Observations made on July 30 (fig. 20) show that flood-tide currents on the bar are rather irregular and reach higher velocities (73 centimeters per second) than in the channel, and that the difference between the velocities at flood and ebb currents is even more pronounced than it is in the channel.

SPAWNING OF OYSTERS AND OCCURRENCE AND DISTRIBUTION OF OYSTER LARVÆ

The time of spawning of oysters in Onset Harbor was ascertained by studying the plankton and noting the first appearance of the oyster larvæ and by examining the gonads of the adult oysters. In the summer of 1927 plankton was collected with a small plankton net made of bolting silk No. 20, and weighted on its under side which bore a protecting strip of linen, so that the net could be dragged over the bottom or towed at any desired level. Five-minute tows were made every day at the surface, along the bottom, and at a level midway between. By towing at the same speed each time a fair estimate of the relative abundance of the larvæ could be obtained. In 1928 quantitative plankton samples were taken by means of a rotary pump and a hose lowered to the desired level. Each time 50 liters of water were pumped and filtered through bolting silk No. 20. In 1927 the first straight hinge oyster larvæ were observed on July 14; the spawning probably occurred a day or two before when the temperature of the water was about 22° C. A few straight hinge larvæ, varying in number from 1 to 8 in a sample, were found in daily plankton samples collected during the second part of July. On July 29–30 their number increased, and from 35 to 80 young larvæ were found in some of the samples. This can be regarded as an indication of a second spawning, which coincided with a second rise of temperature. (See fig. 6.) Small numbers of larvæ were found in plankton during the first half of August; after August 15 they disappeared completely.

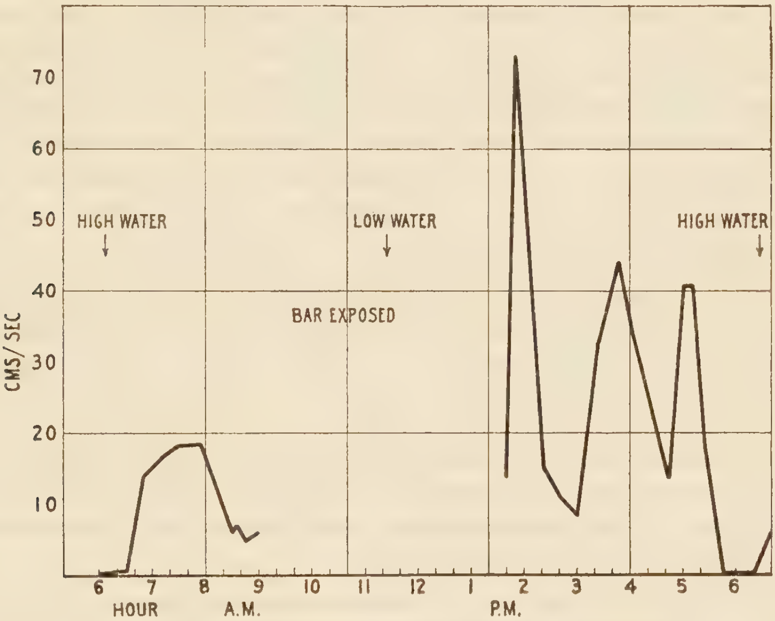

FIGURE 20.—Surface tidal currents at Shell Point bar, July 30, 1928

TABLE 16.—*Occurrence of oyster larvæ in plankton samples collected in Onset Bay during the period July 20–August 28, 1927* [1]

	Surface	Middle	Bottom
Number of samples in which oyster larvæ were found	16	19	14
Maximum number of oyster larvæ found in the sample	75	80	35
Minimum number of oyster larvæ found in the sample	1	1	1
Total number of oyster larvæ found in all the samples	143	298	102
Average number of oyster larvæ per sample	9	15	7

[1] 74 samples that contained no oyster larvæ are not included.

The results of the examination of plankton samples made in 1927 are presented in Table 16, which shows the number of samples containing the oyster larvæ and the maximum and minimum number of the larvæ in the sample. All the samples are grouped in three groups according to the level of water from which they were taken. Of 123 samples collected by Perkins during the period from July 20 to August 28 and examined by the senior author, oyster larvæ of various sizes were found in 49 samples. Altogether, only 543 oyster larvæ were found in all the samples—the maximum number in one sample being 80. It is interesting that, in spite of the scarcity of the larvæ in the plankton samples, setting, as will be shown later, was fair and in the zone between 0.5 and 2 feet above low water varied from 4,200 to 8,000 spat on a bushel of shells. Because of the small number of the larvæ found in plankton, it was impossible to study their vertical distribution and to correlate their occurrence with the physical or chemical factors of the environment. An examination of the table shows, however, that the greatest number of larvæ was found in the middle zone.

Full-grown larvæ were very scarce; out of 48 of them collected between August 3 to 10, 34 were found in the bottom samples. (Table 17). The first spat was observed on shells on August 1, but setting continued until August 15. The heaviest setting apparently occurred on or about August 10.

TABLE 17.—*Occurrence of umbo larvæ in plankton samples taken between August 3–15, 1927*

Date	Number of umbo larvæ in sample				Date	Number of umbo larvæ in sample			
	Surface	Middle	Bottom	Total		Surface	Middle	Bottom	Total
Aug. 3		4		4	Aug. 12	2			2
Aug. 8	1	6	[1] 10	17	Aug. 13			14	14
Aug. 9			2	2	Aug. 15			7	7
Aug. 11	1		1	2					

[1] Large larvæ ready to set.

In the summer of 1928 quantitative plankton samples were taken by McMillin at different stations in the harbor. The first larvæ were noticed on July 2; they had already passed the straight hinge stage and probably were from 4 to 6 days old. On July 12, when the temperature of the water was about 23° C., a distinct change was noticed in the character of the gonads of the adult oysters, indicating that they had released part of their spawn, but very few oyster larvæ of various sizes were found in plankton until the end of July. A clear idea of the scarcity of the oyster larvæ in plankton samples can be gained from an examination of Table 18, which contains the results of the quantitative plankton collection made at frequent intervals at Shell Point. In spite of the scarcity of oyster larvæ the setting on this bar, as will be shown later, was very abundant, varying from 40,000 to 67,000 per bushel of shells. Throughout the spawning season the number of the larvæ collected in various sections of the bay amounted to 146 found in 49 samples. (This figure does not include 43 larvæ collected in 68 samples taken on July 17.)

TABLE 18.—*Occurrence of oyster larvæ in plankton at Shell Point, Onset Harbor, from June 29 until August 3, 1928*

Date	Time	Temperature ° C.	Number of larvæ in 50 liters	Date	Time	Temperature ° C.	Number of larvæ in 50 liters	Date	Time	Temperature ° C.	Number of larvæ in 50 liters
June 29	2.05 p. m.	--------	----------	July 12	5 p. m.	23.8	----------	July 21	8 a. m.	21.8	2
July 2	2.15 p. m.	--------	----------	13	9.54 a. m.	22.8	----------	23	9.50 a. m.	21.7	----------
3	11.45 a. m.	25.5	----------	16	9.30 a. m.	22.6	9	24	8.25 a. m.	22.0	----------
5	2.15 p. m.	24.0	----------	17	10.11 a. m.	24.1	2	25	1.06 p. m.	24.8	9
6	2 p. m.	21.3	----------	18	1.45 p. m.	26.1	9	26	7.19 a. m.	21.9	----------
8	3.06 p. m.	20.4	2	19	10.40 a. m.	23.1	----------	Aug. 2	8.13 a. m.	22.0	----------
9	11 a. m.	22.7	----------	20	12.03 p. m.	24.2	1	3	10.10 a. m.	24.1	----------
10	8.50 a. m.	22.8	2								

A study of the relation between the occurrence of larvæ in plankton and the stage of the tide was made on July 17 at the station located at the end of the shelled area off Shell Point. Observations, consisting in taking quantitative plankton samples from top and bottom, continued without interruption from high slack water at 6.25 a. m. until the beginning of ebb at 6.45 p. m. One can notice from an examination of Table 19 that few oyster larvæ were found only during the morning ebb tide. Unfortunately, the small number of larvæ found in plankton samples makes it impossible to draw a definite conclusion regarding the relation between their behavior and the stage of the tide.

TABLE 19.—*Occurrence of oyster larvæ in plankton at different stages of tide on July, 1928, Shell Point Bar* [1]

Time	Tide	Number of larvæ in 50 liters				Time	Tide	Number of larvæ in 50 liters			
		Straight hinge		Umbo				Straight hinge		Umbo	
		Surface	Bottom	Surface	Bottom			Surface	Bottom	Surface	Bottom
6.25 a. m.	Ebb	2	0	0	0	8.40 a. m.	Ebb	3	1	1	1
6.40 a. m.	do	3	0	0	3	9 a. m.	do	3	0	0	0
7 a. m.	do	3	0	3	0	9.20 a. m.	do	0	0	0	0
7.20 a. m.	do	2	0	1	0	9.40 a. m.	Low slack	0	0	0	0
7.40 a. m.	do	0	0	0	0	10 a. m.	do	0	0	0	0
8 a. m.	do	4	2	1	1	10.20 a. m.	Flood	0	0	0	0
8.20 a. m.	do	3	2	1	2	10.40 a. m.	do	0	0	0	0

[1] No oyster larvæ were found in 48 samples taken at 20-minute intervals from 11 a. m., until 6.40 p. m.

An attempt to study horizontal distribution of the larvæ in a limited area of the bay was made on July 30; plankton samples were taken from the surface, middle zone, and bottom at seven stations along the line between Shell Point and the point on the southern shore of the bay. (Fig. 15.) The result of the observations, presented in Table 20, show that there was a slight concentration of the oyster larvæ in the vicinity of Shell Point.

TABLE 20.—*Horizontal and vertical distribution of oyster larvæ near Shell Point, Onset Bay*

[Sample of 50 liters]

Depth	Stations[1]						
	A	a	b	c	B	d	e
Surface	9	14	8	3	2	1	2
Middle	------	------	4	------	------	3	------
Bottom	21	2	2	3	9	1	------

[1] For location of stations see Figure 15.

The failure to take large numbers of oyster larvæ in the plankton during the two consecutive summers can be explained by either a faulty method of collecting or the behavior of the larvæ. Experiments carried out by the bureau in Great South Bay, where many thousands of oyster larvæ were collected by pump or in plankton tows, show that in this body of water, with very small range of tide, larvæ are easily obtainable by either method. It is, therefore, permissible to assume that the failure to collect oyster larvæ in plankton in Onset Bay was due to their behavior. The fact that at Shell Point the velocity of flood current is greater than the velocity of the ebb current may explain the absence of larvæ from plankton during the flood tide. It is quite probable, however, that besides the velocity of the current other conditions govern the behavior of the larvæ. The problem calls for an experimental study that should be carried out under controlled laboratory conditions. It is doubtful that it could ever be solved by field observations where on account of the complexity of conditions and the impossibility of eliminating various factors, the results obtained are often contradictory and their interpretation is difficult.

The conclusion can be drawn from the examination of plankton collections that the small number of larvæ, or even their absence in plankton samples taken in the inshore waters with strong tidal currents, does not necessarily show the failure of oysters to spawn in this locality and can not be regarded as indicative of ensuing poor setting. In the attempt to predict setting in such a region, more weight should be given to the conditions of the gonads of oysters and to the temperature of the water over the oyster bottoms than to the presence of free swimming larvæ.

After the 15th of July, shells from each bar were examined daily to determine the exact time of setting. On July 23 full grown larvæ were found in the bottom sample taken at Stony Bar. (Station *G*, fig. 15.) The following day a few spat were found on shells at Manoman Bar. (Station *C*, fig. 15.) On July 25 spat appeared on the shells all over the bay, and on July 26 the setting was complete, or at least the larvæ that attached after this date were not numerous enough to make themselves evident.

EXPERIMENTS WITH SPAT COLLECTORS

The commercial seed catching areas in Onset Bay are located on flat bars between mean low water and 2 feet above that level. The oystermen have learned by practice to restrict their shelling operations to these limited sections of the bay and to scatter the shells over the bars only in the zone which is exposed at low tide. No cultch is planted beyond low-water mark, where, according to the opinion of local oystermen, no setting takes place.

A series of experiments with wire-bag collectors was devised to determine the extent of the setting area and to find out the effect of elevation (with the reference to the low-water mark) upon the density of setting. In 1927, 950 bags were planted at 9 stations; they were placed either singly on the bottom, stacked in a group of 6 or 8 (fig. 21, 22), or piled irregularly on the bars. In order to determine the level of maximum setting, 400 bags were arranged in 8 rows at Shell Point extending across the bar from 1 foot below low-water mark to 4 feet above. After September 1, 10 bags were taken at random from every row, emptied, the shells were well mixed up, and 1 peck of them taken for counting the spat. The results of the counts are presented in Table 21. Although there was a considerable variation in the number of spat in the bags of the same row, it is evident from an examination of Table 21 and Figure 23 that the maximum density of setting occurred in the zone of from 1. 5 to 2 feet above low-water mark. No setting was found at high-water level (4 feet). It has been noticed also that the spat was well distributed throughout each bag, only about 10 per cent of shells being blank. From a commercial point of view, the setting in the bags planted in various sections of the bar was fair; in the zone between low-water mark and 2 feet above, it averaged 5, 898 spats to a bushel. Setting on shells thrown on the bar averaged 6,990 spats to a bushel and was more uniform than it was in the individual bags. (Table 22.) This shows that both loose shells and those in the bags have approximately the same concentration of spat, but taking into consideration the area of the bottom covered by one bushel of scattered shells and by one bag, the productivity in the bags was much higher. On the surface of Shell Point bar in the zone between 0. 5 and 2 feet above low water, there was on the average 86 scallop shells over each square foot, or about 0. 6 bushel of shell to a square yard (there were about 1,300 scallop shells to one bushel) bearing about 4,200 spats. Three bags laid horizontally over the area of 1 square yard at the same level caught on the average 5,900 spats to a bushel of shells or 17,700 spats per square yard. Thus the productivity in the bags was four and two-tenths times that of the shells scattered over the same area. By stacking the bags in various formations it is possible to put 8 or 10 of them over one square yard of the surface of the bar, thus utilizing the whole height (4 feet) of the setting zone and increasing its productivity materially.

TABLE 21.—*Vertical distribution of setting (number of spat per bushel) in Onset Bay, near Shell Point, 1927*

[Wire-bag collectors]

Bag No.	Position of the bag in relation to low water							
	−1 foot	Low water	+0. 5 foot	+1 foot	+1. 5 feet	+2 feet	+3 feet	+4 feet
1	2, 000	3, 100	2, 200	4, 700	12, 200	6, 700	2, 500	No set.
2	3, 100	6, 900	2, 800	3, 400	7, 800	7, 000	1, 400	Do.
3	2, 000	2, 700	6, 000	3, 700	3, 200	9, 400	1, 200	Do.
4	1, 300	3, 100	6, 800	4, 200	7, 900	12, 900	1, 100	Do.
5	3, 500	5, 300	7, 500	5, 900	8, 200	4, 800	1, 100	Do.
6	2, 300	4, 500	6, 200	3, 600	8, 400	4, 400	3, 500	Do.
7	2, 200	4, 000	6, 900	3, 000	6, 200	12, 600	3, 000	Do.
8	1, 900	4, 900	6, 600	5, 100	4, 200	6, 000	2, 200	Do.
9	900	5, 800	6, 800	4, 500	10, 700	4, 000	1, 600	Do.
10	1, 400	4, 800	6, 100	4, 000	6, 200	2, 000	4, 000	Do.
Average	2, 050	4, 510	5, 790	4, 210	8, 000	6, 980	2, 160	

TABLE 22.—*Number of spat per bushel of scallop shells taken between 0.5 and 2 feet above low-water mark at Shell Point Bar, Onset, 1927*

Sample number	Spat per bushel	Sample number	Spat per bushel	Sample number	Spat per bushel	Sample number	Spat per bushel
1	6,800	4	7,500	7	6,400	10	6,600
2	7,700	5	7,200	8	7,200	Average	6,990
3	6,100	6	6,600	9	7,800		

The results of setting experiments on Middle and Stony Bars are shown in Table 23. From each bar 10 bags were taken at random from an area just above low water and the number of spat was counted. The results show that setting in the bags was heavier than on loose shells, although the difference was not great. Several bags filled with oyster shells and lowered to 5 or 6 feet below low-water level at the side of the main channel in Onset Bay caught a set averaging 8,000 to a bushel. These observations show that although the zone of heaviest setting occurs above low-water mark on the exposed bars, certain areas under water can be successfully utilized by planting bags filled with oyster shells.

TABLE 23.—*Setting on Middle and Stony Bars, Onset Bay, 1927*

Location	Number of spat per bushel (bags)			Number of spat per bushel (loose shell)		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Middle Bar (station F)	11,200	19,300	5,600	7,700	9,700	6,100
Stoney Bar (station E)	8,400	11,800	5,200	6,300	10,500	3,700

Experiments carried out in 1928 were the repetition of those made in the summer of 1927 and were undertaken with the purpose of checking up the results obtained in the previous year. Over 100 wire bags filled with oyster or scallop shells were planted on Shell Point and at Sherman Bar (fig. 15, *A*, *D*); over 700 bags were planted also on Shell Point by Schroeder & Besse Co. All the bags were examined by McMillin in August and the setting on them was recorded. At Shell Point 21 bags were placed in 3 lines (fig. 15) extending from the middle of the area devoted to commercial seed production (about 1.5 feet above low water) to 3 feet below low water. The bags on line 1 which ran lengthwise of the bar and off the end of the point in a southeasterly direction were placed about 12 feet apart. Along lines 2 and 3 which ran at right angles to the eastern side of the bar the bags were about 4 feet apart below low water and 6 feet apart above low water. Bags on lines 1 and 3 contained oyster shells; those of line 2 were filled with scallop shells. One line (No. 4) comprising 8 bags filled with oyster shells was placed on Sherman Bar, Onset Island. In August, when the set was large enough to be easily seen with the naked eye, the bags were taken up and the number of young oysters was counted. In 3 bags the spat on every shell was counted but it was found that 1 peck of well-mixed shells gives a representative sample, and that by this way the number of seed per bushel could be calculated with an error of less than 5 per cent. The results of the experiments are presented in Table 24 and Figure 23. The maximum setting at Shell Point occurred about 1 foot above low-water mark where the number of spat per bushel varied from 41,800 to 68,700 spat per bushel. Setting below low-water mark was less heavy, varying from 2,000 to

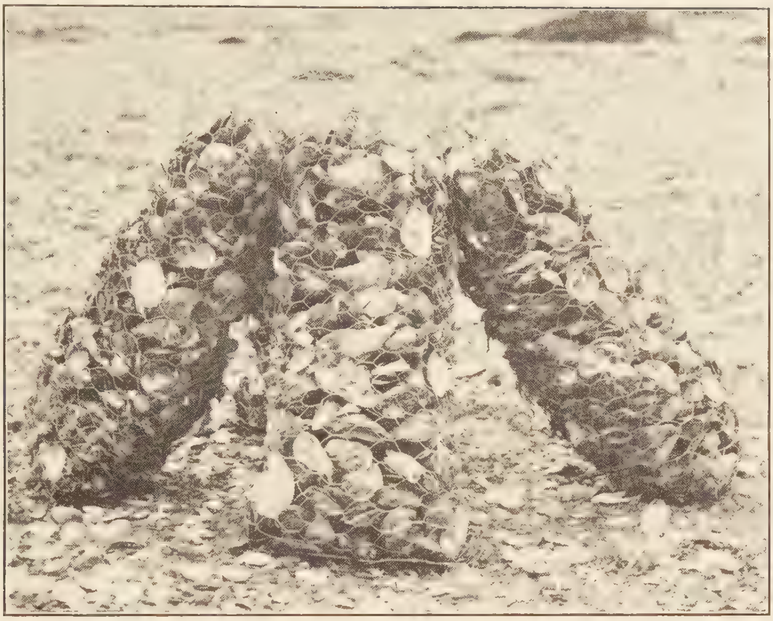

FIGURE 21.—A group of four wire bag collectors, Shell Point, Onset Bay

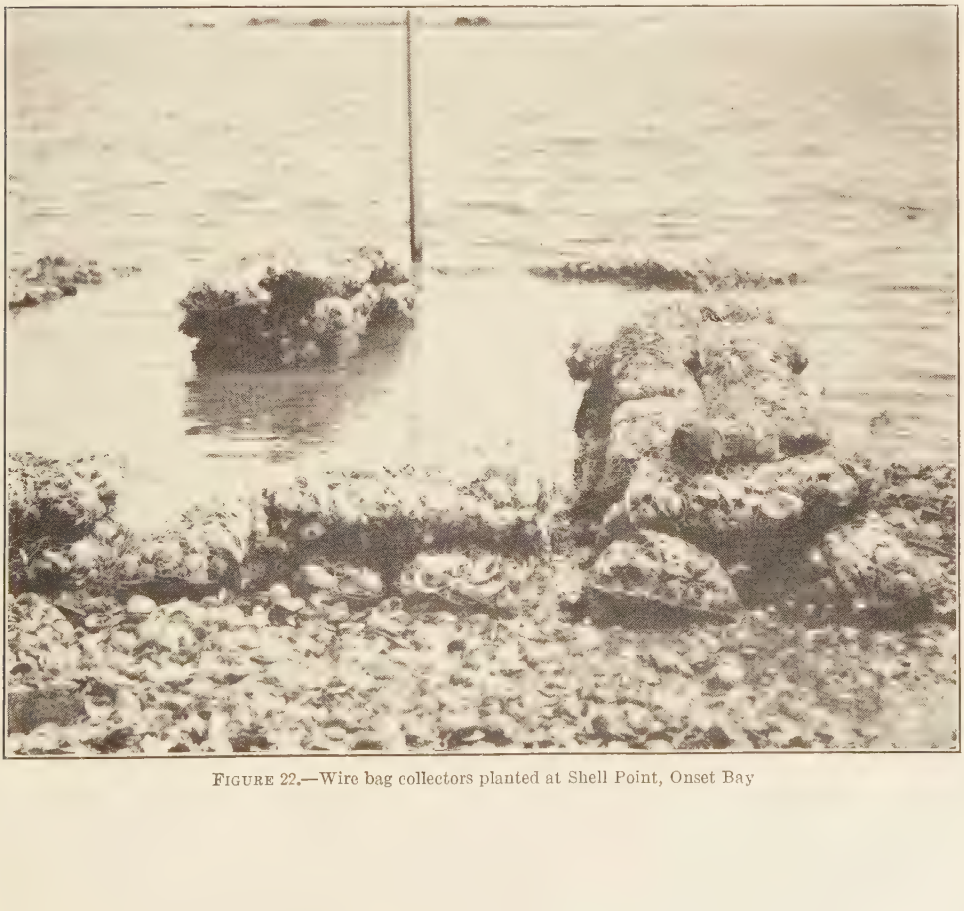

FIGURE 22.—Wire bag collectors planted at Shell Point, Onset Bay

27,700 spat per bushel. No significant differences were observed in setting along the three different lines.

TABLE 24.—*Vertical distribution of set in Onset Bay, 1928*

[Wire-bag collectors]

Height in relation to low water (feet)	Spat per bushel				Height in relation to low water (feet)	Spat per bushel			
	Shell Point Bar			Sherman Bar		Shell Point Bar			Sherman Bar
	Line 1	Line 2	Line 3	Line 4		Line 1	Line 2	Line 3	Line 4
+2.0	----------	----------	----------	1,900	−0.5	----------	27,700	----------	11,900
+1.5	----------	----------	----------	5,700	−1.0	11,400	2,300	----------	----------
+1.3	----------	----------	41,800	12,400	−1.5	8,600	5,100	14,700	7,400
+1.0	44,800	68,700	64,400	10,800	−2.0	----------	3,800	11,600	----------
+0.5	48,300	61,200	55,400	17,300	−2.5	10,500	----------	19,200	----------
Low water	33,700	----------	----------	----------	−3.0	4,800	2,000	----------	----------

At Sherman Bar (line 4, Table 24) the largest number of seed (17,300 per bushel) was found at 0.5 foot above low water. This level is about 1.5 feet below the area upon which shells were scattered by commercial oystermen. It is obvious that the productivity of this bar would be materially increased by grading it down until its entire surface is 1.5 below the present planted area. In most of the bars the areas upon which shells are planted by the oystermen do not extend beyond 1.5 feet below low water; yet, as the observations show, a fairly good set can be obtained at 3 feet

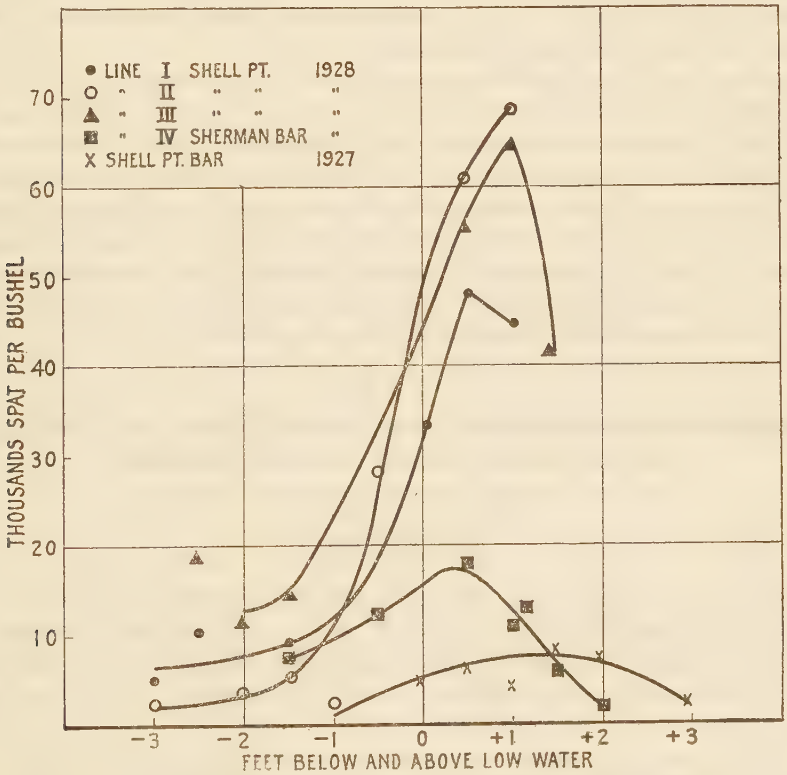

FIGURE 23.—Vertical distribution of setting in wire bag collectors planted in Onset Bay, 1927 and 1928

below low water and probably deeper. Thus the productivity of all the bars can be greatly increased by extending the shelled areas below low water and by planting bags on muddy bottoms where loose shells would be lost.

An attempt was made to catch set in a very shallow body of water known as Shell Point Cove, located just above Shell Point. The cove, which is locally known as Sunset Bay, has never been used for collecting of seed. There is a general opinion, based on the experiments made several years ago by local oystermen, that the bay is unsuitable for catching of seed and that the shells thrown over its bottom never will catch any spat. Several bags planted there in July 1928, 1 and 2 feet below low water, caught however, from 6,800 to 7,900 spat per bushel.

It appears that the whole area of Shell Point Cove, comprising several acres of barren bottom, can be utilized for catching seed oysters and can be converted into productive ground.

In 1928 the number of blank shells (having no spat) in the bags was not over 1 per cent as compared to 10 per cent of blanks found in the previous summer. The smaller percentage of blank shells in 1928 is undoubtedly due to much heavier setting during that year. An exception to this was found in the bags planted 3 feet or more below low-water mark; 75 per cent scallop shells and 5 per cent of oyster shells from these bags having no spat. In the localities where setting was poor, all the spat in the bags was found on the outer shells only.

It is interesting to note that in the summer of 1927 the zone of the most intensive setting was about three-fourths of a foot higher than in 1928. The exact cause of this difference is difficult to ascertain, yet it seems probable that it was due to a range of tide during the time of setting. In 1927 setting took place between August 1 and 19 with the probable maximum around August 11–12 when the height of the tide was 4.2 to 4.4 feet. In 1928 setting occurred about July 26 when the height of the tide was only 3.3 feet. Unfortunately lack of knowledge of the conditions governing the behavior of the larvæ during their setting does not justify any further speculations as to the possible causes of the variation in the zone of setting.

IV. EXPERIMENTS IN SEED-OYSTER PRODUCTION AND COLLECTION IN MILFORD HARBOR, CONN., 1925–1928

By H. F. PRYTHERCH

INTRODUCTION

Milford Harbor is one of the typical oyster producing inshore areas of the State of Connecticut. When the town of Milford was settled in 1639, oysters and clams were found in abundance along its shores, and the fishing of oysters, which was free to everyone, soon lead to depletion of the beds and the passage of the first oyster legislation in 1784. This law gave to the towns in the State the power to regulate the fisheries of oysters and clams within their respective limits and resulted in various regulations restricting the quantity to be taken and the season when oysters could be harvested. These measures prevented overfishing to some extent and were followed in 1845 by legislation which allowed for the first time the transplanting and laying down of oysters from other States. In 1855 an important law known as the two acre law was passed which granted to any citizen such an area of bottom for the cultivation of shellfish, which at the time was considered to be all that one man could attend to. For the next 10 years oyster cultivation was confined to the shallow waters of the rivers and harbors and consisted in the transplanting and growing of seed from the natural beds and the planting of shells for the collection of set or spat.

The success of oyster culture on this small scale and the discovery in 1865 that the deeper waters of Long Island Sound were suitable for growing oysters and collecting spat soon led to the development of extensive deep-water oyster farming in Connecticut. By 1880 the early method of oystering on 2-acre plots with dug out canoes and tongs was supplanted by a great system of deep-water oyster farms extending from Greenwich to Branford, on which were operated steam-driven vessels capable of dredging from 200 to 800 bushels of oysters a day. Thousands of acres of ground in the harbors and sound were leased to the enterprising oyster growers who converted these barren unproductive bottoms into valuable oyster growing areas. The acreage leased from the State for oyster culture in 1881 was 33,988; in 1910, 74,514; and since has declined to 54,212 in 1927. The production of oysters in Connecticut increased rapidly with the development of oyster farming, reaching a maximum of 3,948,100 bushels in 1908, which was valued at $2,582,940. Since then oyster production has shown a steady and alarming decrease, the chief cause of which has been the lack of seed oysters and the repeated failure of setting. This condition has led to the recent investigations conducted by the bureau at Milford, Conn.

One phase of this investigation dealt with the physical conditions affecting the spawning of the oyster and the distribution and setting of the larvæ (Prytherch, 1929). The second phase of the work, which is taken up in the present paper, deals with the experiments for increasing the production of seed oysters and improving methods for collecting them. The general plan of these experiments was to demonstrate the method of restoring inshore grounds to their former condition as prolific oyster setting areas through the establishment of spawning beds and the use of improved methods of spat collection. Various types of spat collectors were planted on the tidal flats and in the channel, arranged in different formations. Setting on the collectors was studied to determine the best setting areas and the zone in which the greatest numbers of spat could be collected, and the results obtained on each collector, the cost of material, handling expense, durability, etc., was compared to determine which type of collector is the most efficient, cheapest, most practicable, and best adapted for use on a commercial scale.

The experiments which are discussed here were made in 1925, 1926, 1927, and 1928 in cooperation with the Connecticut Oyster Farms Co., who generously supplied and planted oysters for a spawning bed and furnished men and boats for putting out the collectors. The spawning bed, containing approximately 1,000 bushels of oysters, was located in the harbor just below the laboratory and was situated partly on the tidal flats and partly in the channel. The harbor is practically unpolluted so that it was possible by its rehabilitation to study the oyster in an environment very similar to that in which it thrived in years past.

PHYSICAL CONDITIONS IN MILFORD HARBOR

Milford Harbor is located on the Connecticut shore of Long Island Sound and lies about half way between two great oyster producing centers, Bridgeport and New Haven. The general topographical and hydrographical features of the harbor are shown in Figure 24. This small body of water covers approximately 80 acres, about half of which consists of tidal flats which are exposed at low tide. The water in the harbor comes from two sources, from the Wepawaug and Indian Rivers which bring down fresh water from the surrounding country, and from Long Island Sound, from which brackish waters are carried into the harbor by the flood tides.

The potential value of any body of water for the propagation and growth of shellfish depends largely upon the physical conditions which exist there. The conditions found in Milford Harbor are characteristic of those found in most of the other harbors and estuaries which empty into Long Island Sound and which have been found to be very favorable localities for the reproduction and growth of the oyster, quahaug, and soft clam. A brief résumé is given here of the observations which were made in 1925 and 1926 regarding the physical conditions of the water;

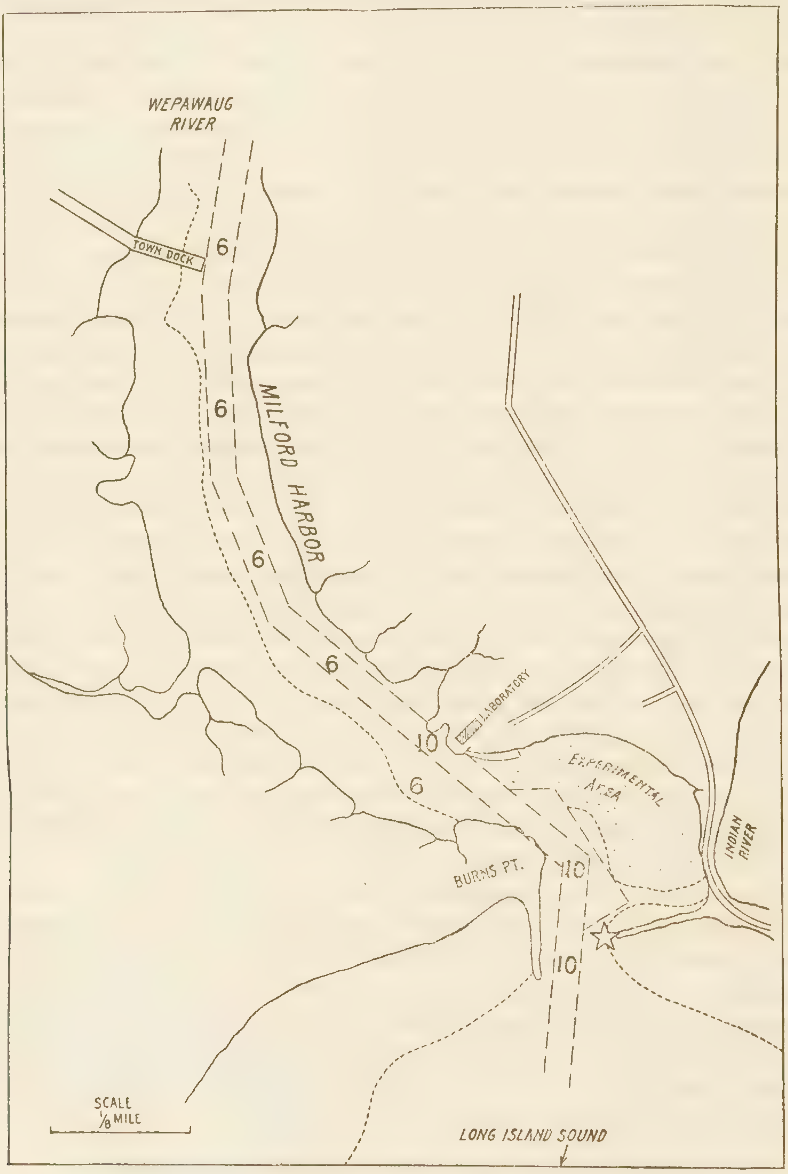
WEPAWAUG RIVER
TOWN DOCK
6
6
MILFORD HARBOR
6
6
10
LABORATORY
EXPERIMENTAL AREA
6
BURNS PT.
10
10
INDIAN RIVER
SCALE
1/8 MILE
LONG ISLAND SOUND

FIGURE 24.—Milford Harbor, Conn.

for a more detailed discussion of the various factors the reader is referred to the author's previous paper (Prytherch, 1929).

TEMPERATURE

The temperature of the water in Milford Harbor was recorded continuously during the summer months by means of a thermograph set up at the laboratory. The daily variations in water temperature and its trend during the summers of 1925 and 1926 are shown in Figure 25. In 1926 and 1927 the mean water temperature for July and August was slightly lower than in 1925 as shown in Table 25. The average of the three years gives us a mean monthly temperature of 18.7° C. for July and 20.5° C. for August.

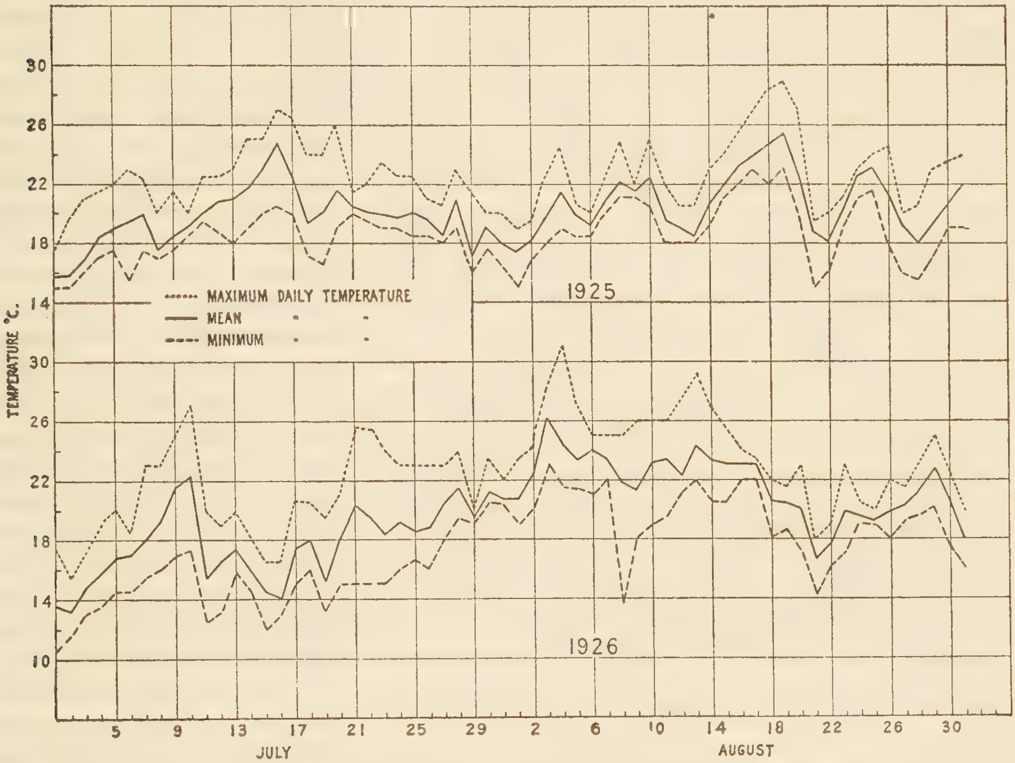

FIGURE 25.—Maximum, minimum, and mean daily temperature of the water, 1925 and 1926, Milford Harbor, Conn.

TABLE 25.—*Water and air temperatures in Milford Harbor during July and August, 1925 to 1927* [1]

Year	Mean monthly temperature, ° C.			
	July		August	
	Water	Air	Water	Air
1925	19.7	21.8	20.8	21.6
1926	17.8	22.0	21.6	21.8
1927	18.5	22.4	19.0	19.3
Average for 3 years	18.7	22.0	20.5	20.9

[1] The normal air temperature for this region is 22.2° C. in July and 21.1° C. in August, according to the records of the U. S. Weather Bureau at New Haven, Conn.

Considerable fluctuation in water temperature, characteristic of Milford Harbor and similar inshore waters is the result of changes in weather conditions and stage of tide. The daily and hourly fluctuations are at once apparent from Figure 25 which shows the maximum and minimum temperature for each day together with the mean. Variations in the daily range of temperature amounted to from 1° C. to 11.5 ° C. The highest temperature invariably occurred at the time of low water while the lowest temperatures were found near the time of high water when the greatest quantity of water had been brought in by the flood tide from Long Island Sound. The typical hourly changes in temperature that occur during a tidal cycle are shown graphically in Figure 26 for several days in 1926. The highest water temperature recorded by the thermograph during July and August was 31° C. and the lowest 10.5° C. In the studies of thermal conditions it was found that exposure and flooding of the tidal flats increase greatly the exchange of heat between the water, land, and air and are responsible for the large fluctuations in temperature of the water.

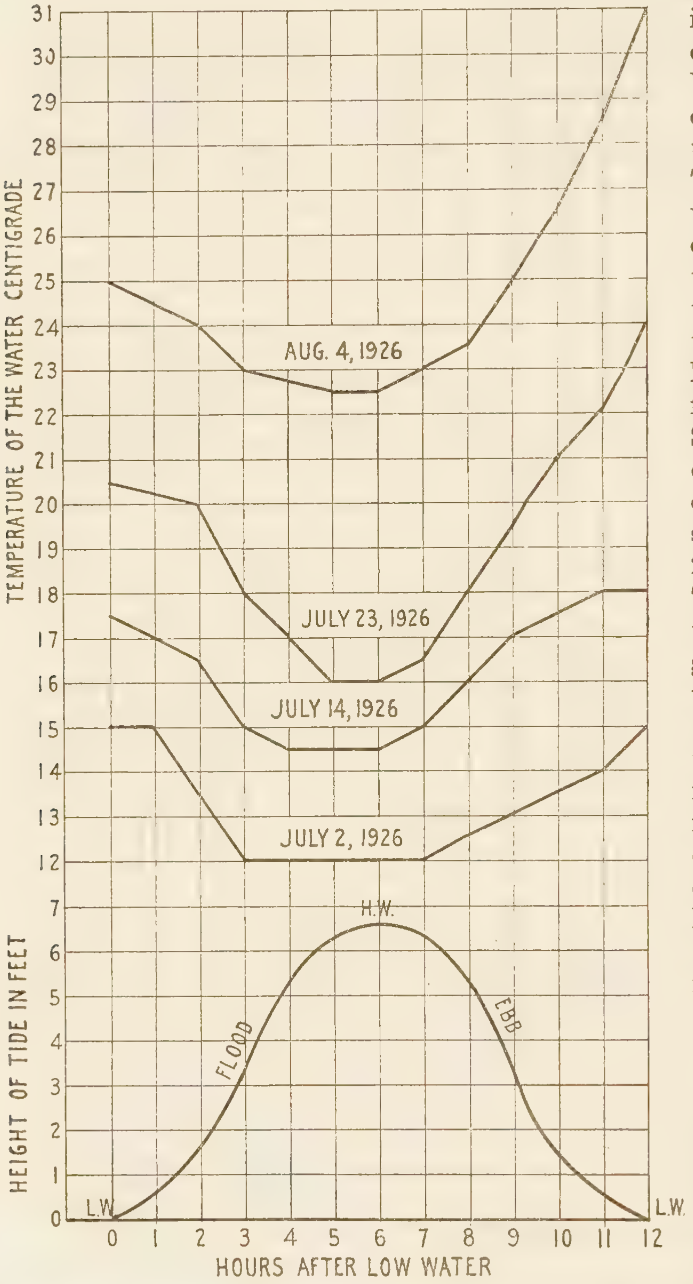

FIGURE 26.—Fluctuations in water temperature during tidal cycle, Milford Harbor

SALINITY

The salinity of the water in Milford Harbor depends upon two main factors, namely, the discharge of fresh water by the Wepawaug River and the inflow of brackish water from Long Island Sound. The distribution of salinity in the harbor is shown in Figure 27 for a series of observations that were made during flood tide on July 15, 1925. During the summer the range of salinity was from 4.50 to 28.66

per mille though as a general rule the daily fluctuation was from 25 to 28 per mille. The changes in salinity that occur during a complete tidal cycle are shown in Figure 28 together with the observations on temperature and pH. The results obtained in this series of observations, which were made on August 24, 1925, from time of low water to high water and back again, are given in Table 26.

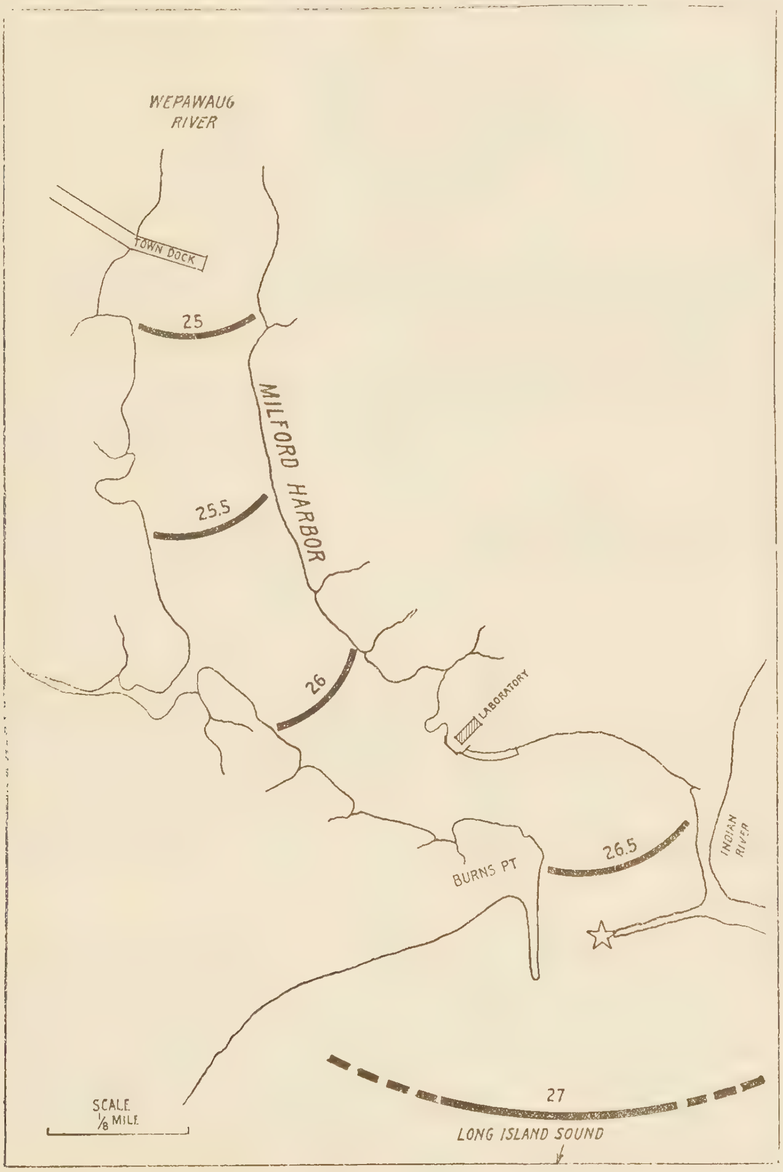
WEPAWAUG RIVER
TOWN DOCK
25
MILFORD HARBOR
25.5
26
LABORATORY
26.5
INDIAN RIVER
BURNS PT
27
SCALE 1/8 MILE
LONG ISLAND SOUND

FIGURE 27.—Horizontal distribution of salinity, Milford Harbor, July 15, 1925

TABLE 26.—*Effect of tide on physical conditions in Milford Harbor, August 24, 1925*

Tide	Time	Depth, feet	Salinity, per mille	Temperature, ° C.	pH	Tide	Time	Depth, feet	Salinity, per mille	Temperature, ° C.	pH
Low water	8 a. m.	0	25.35	20.9	7.2	High water	2 p. m.	15	28.10	21.0	7.4
Do	do	10	27.66	21.8	7.4	Ebb	4 p. m.	0	27.66	23.3	7.6
Flood	10 a. m.	0	26.78	21.4	7.4	Do	do	13	28.12	22.0	7.4
Do	do	11	28.04	20.0	7.8	Last ebb	6 p. m.	0	26.18	24.2	7.5
Do	12 m.	0	27.88	21.9	7.8	Do	do	12	27.82	23.0	7.3
Do	do	13	28.10	20.2	7.6	Low water	8 p. m.	0	25.50	24.0	7.3
High water	2 p. m.	0	27.75	22.2	8.0	Do	do	10	26.75	23.0	7.2

Since the range of tide on this particular date is but 0.2 foot above the mean range, the changes in water conditions can be regarded as intermediate between those which would occur with extreme spring or neap tides. Changes in salinity are least at the time of neap tides and greatest with spring tides. The differences in the salinity between top and bottom samples were generally less than 1 per mille and naturally were greatest above the town dock, where fresh water entered the harbor from the Wepawaug River, and least at the mouth of the harbor. Occasionally, however, extreme differences were found following heavy rains or with the change of tide from low water to flood. An example of the first instance occurred on July 9, 1925, when the surface was covered with a layer of water from 6 inches to a foot deep which was practically fresh, or of a salinity of about 5 per mille, while that on the bottom was 25 per mille.

HYDROGEN-ION CONCENTRATION

The water in the harbor is naturally alkaline and ranges during the summer from pH 7.2 to 8.4. During July an average pH value of 7.8 was observed, while in August the readings became higher and ranged from 8.0 to 8.2. The lowest pH values were found in samples taken at low tide following heavy rains and the highest in afternoon samples taken near the time of high water. An example of the surface and bottom changes in pH during a complete tidal cycle is shown in Figure 28 and Table 26.

TIDES AND CURRENTS

The vertical and horizontal movement of the water as a result of the tide is important because it produces considerable variation in its temperature, salinity, and pH. In Milford Harbor the mean range of tide is 6.6 feet and the spring range 7.7 feet. During spring tides the maximum range recorded during the summer was 9 feet, while with neap tides the minimum range was 4.2 feet. The tide here is of the semidiurnal type with two high and two low waters occurring during each tidal day, with little difference between the morning and afternoon tides and their duration of rise and fall, each of which is about 6 hours.

From a biological point of view both the rise and fall of the water and the horizontal movement or tidal current are of considerable importance. In Milford Harbor the tidal movement is of the stationary-wave type, the strength of the current coming midway between high and low water while the slack of the current comes near the times of high and low water. The tide and current relationships for Milford Harbor entrance are shown in Figure 29. The tidal currents vary in strength from day to day in accordance with the regular changes in the range of tide. The strongest currents come with the spring tides of full and new moon and the weakest currents with the neap tides of the moon's first and third quarters. During the spring tides the flood current in Milford Harbor attains a maximum velocity of 33 centimeters (1.1 feet) per second and the ebb current 45.7 centimeters (1.5 feet) per second. With neap tides considerably less water passes in and out of the harbor and the velocity of the flood current at strength is 24.4 centimeters (0.8 feet) per second and the ebb current 40.6 centimeters (1.3 feet) per second. The tidal currents here are of the rectilinear or reversing type; that is, the flood current running in for a period of approximately 5 hours and 30 minutes and the ebb current running out for a period of 6 hours. The ebb current has a greater velocity and period of duration than the flood current because of the river water discharged into the harbor. Using the formula given by Marmer (1925) it is estimated that currents of such strength as those at the entrance of Milford Harbor would transport a floating object approximately 21,100 feet during the ebb flow of 6 hours and return it but 15,600 feet during

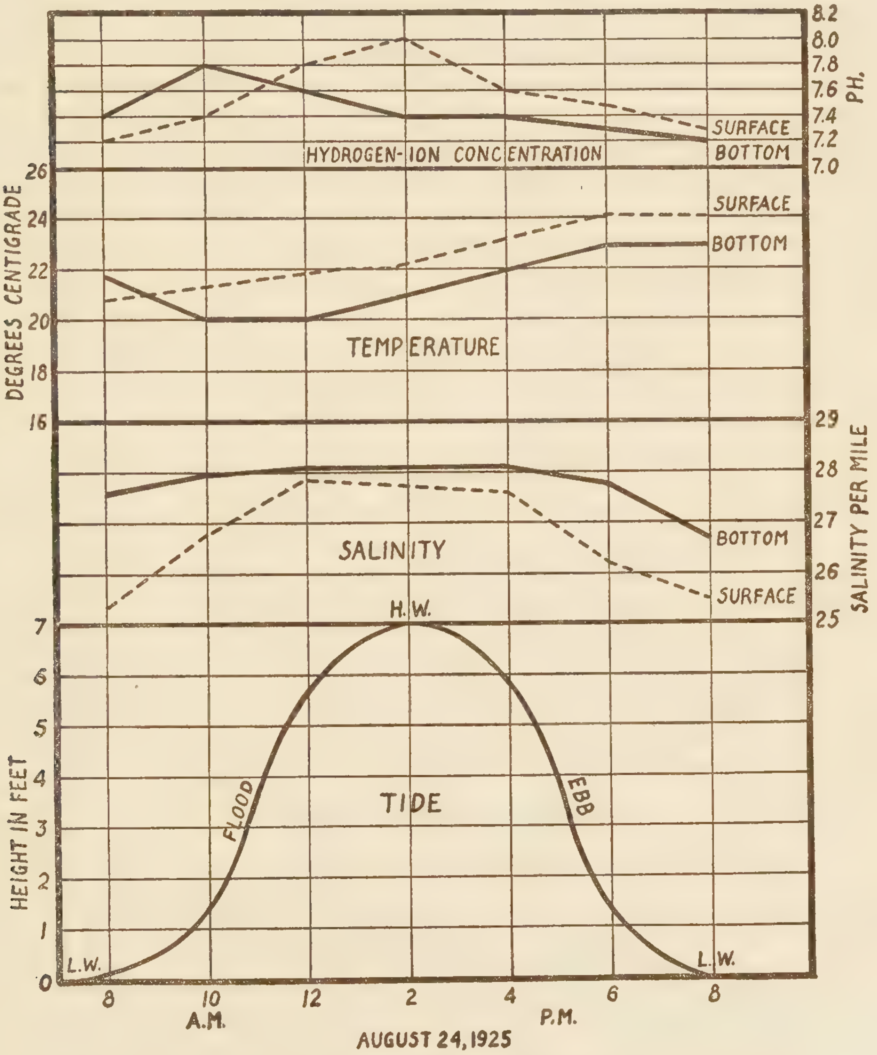

FIGURE 28.—Temperature of the water, pH, and salinity during tidal cycle, Milford Harbor

the flood. Experiments with drift bottles demonstrated clearly the dominant drift of the ebb current and showed that an object floating freely in the water would be carried out of the harbor the first day by the tidal currents and would never be transported back to it. This condition has an important bearing on the distribution and occurrence of the oyster larvæ in the harbor which will be discussed later.

The most important effect of the tide was found to be in regard to its influence on water temperature. The movement of the water over the tidal flats increases greatly the effect of solar radiation and air temperature on water temperature and accelerates the exchange of heat between the air, land, and water. It was found that during full moon tidal periods in July the water temperature increased from approximately 15° C. to 25° C. in a period of 15 days. During these periods the range of tide is greater than the mean range, and a much larger area of tidal flats are brought into contact with the water. This condition combined with the intense solar radiation and the high air temperature that occurs at this time of year, is responsible for the heating of the water to a temperature of 20° C. and above, which is necessary for oyster spawning.

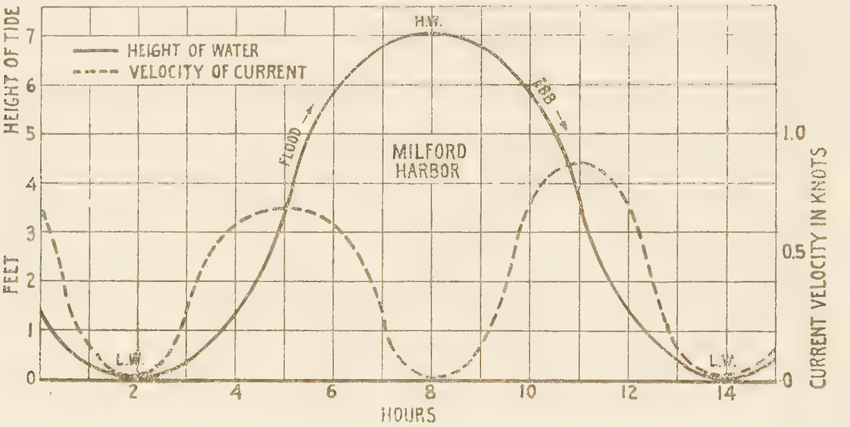

FIGURE 29.—Current velocity and height of tide, Milford Harbor

BIOLOGICAL OBSERVATIONS

RIPENING OF THE GONADS AND SPAWNING

Oysters in Milford Harbor were first found to be ripe during the period extending from July 1 to 15—the exact date varying in accordance with water temperatures during the preceding months. When the water and air temperatures from April to July were above normal, as in 1925, the oysters were found to be ripe much earlier and contained a greater quantity of spawn than they did in 1926 or 1927, when the temperature for the same period was below normal. The layer of reproductive tissue surrounding the liver was found to vary in thickness from 1.5 centimeter in 1925 to 0.5 of a centimeter in 1926 and 1927. The gonads of the oysters were found to be soft and ripe on July 1 in 1925, while this condition was not reached until the middle of the month during the other two years.

The time of oyster spawning depends largely upon the attainment of a water temperature of at least 20° C. In Milford Harbor there are generally two spawnings; the first being very light and occurring about the middle of July, while the second or heaviest spawning takes place about the 1st of August. In 1925, 1926, and 1927, the time of spawning was found to vary somewhat in accordance with water temperature and tidal conditions. Heavy and complete spawning of the harbor oysters occurred on July 13 in 1925, but not until August 1 in 1926, and July 22 in 1927. The spawning in 1925 was over two weeks earlier than the average time of spawning observed during the past seven years and was due to the higher water temperature and the early ripening of the oysters during July of that year. The heaviest spawning was found to occur after the water had reached and maintained a temperature of from 20° C. to 21° C. for a few days. During all three years the spawning took place at the end of the "full moon tidal period" or in other words from seven to eight days after the time of the July full moon. It was observed also that the oysters spawned near and at the time of high tide, when the water was found to be more alkaline and had a pH value of 7.8 and above. On the days when spawning occurred it was found that the water had attained for the first time (since ripening of the oysters) an average temperature of 20.7° C.

LARVAL PERIOD

Quantitative plankton collections were made regularly to study the occurrence and distribution of the oyster larvæ. In these collections the larvæ were found to be relatively scarce and in many cases were totally absent. The number of larvæ collected in the harbor was extremely small in proportion to the intensity of setting which occurred there later. For example, the total number of larvæ collected over the spawning bed in a period of several weeks scarcely reached a hundred, while in the same spot many hundred thousand were later found attached to the collectors. In a series of plankton collections made during several tidal cycles it was found that the oyster larvæ were most abundant at the time of low slack water and gradually disappeared as the tide began to run flood. The distribution of the larvæ in relation to the stage of tide on August 11 to 13, 1926 is shown in Figure 30. When the flood current had developed a velocity of 18.3 centimeters (0.6 foot per second, practically no larvæ could be found swimming in the water while samples from the bottom collected at the same time were found to contain an average of 14 larvæ per square foot of surface. The finding of the oyster larvæ on the bottom at certain stages of the tide shows that they are not passive planktonic forms and, therefore, are not subject to wide dispersal by the tides and currents. By remaining on the bottom during the greater part of the larval period and by limiting their swimming activities to the tidal periods when horizontal movement of the water is least, the oyster larvæ are able to remain and set on and near to the spawning bed which produced them.

One of the important questions that has presented itself in the development of methods for seed oyster production has been, "Where does the spawn, or larvæ, from a bed of oysters finally become attached or set?" The increased production of oyster larvæ and spat in Milford Harbor following its rehabilitation showed definitely during the past three years that the oyster larvæ are not distributed far from the spawning bed by the currents—the predominating drift of which is out of the harbor. The final distribution of the larvæ was determined easily by studying the relationship of the setting areas to the spawning bed. It was found that the majority of the larvæ set within a radius of 300 yards from the center of the spawning bed, and that the greatest number of spat per square inch or per shell was found on the bed and within a 100-yard radius. As indicated by setting, the larvæ were distributed both above and below the spawning bed and attached in greater numbers on the areas which were just below or in the direction of the sound. Though the intensity of setting varied from year to year the distribution of the larvæ was always found to have this same relation each year to the spawning bed.

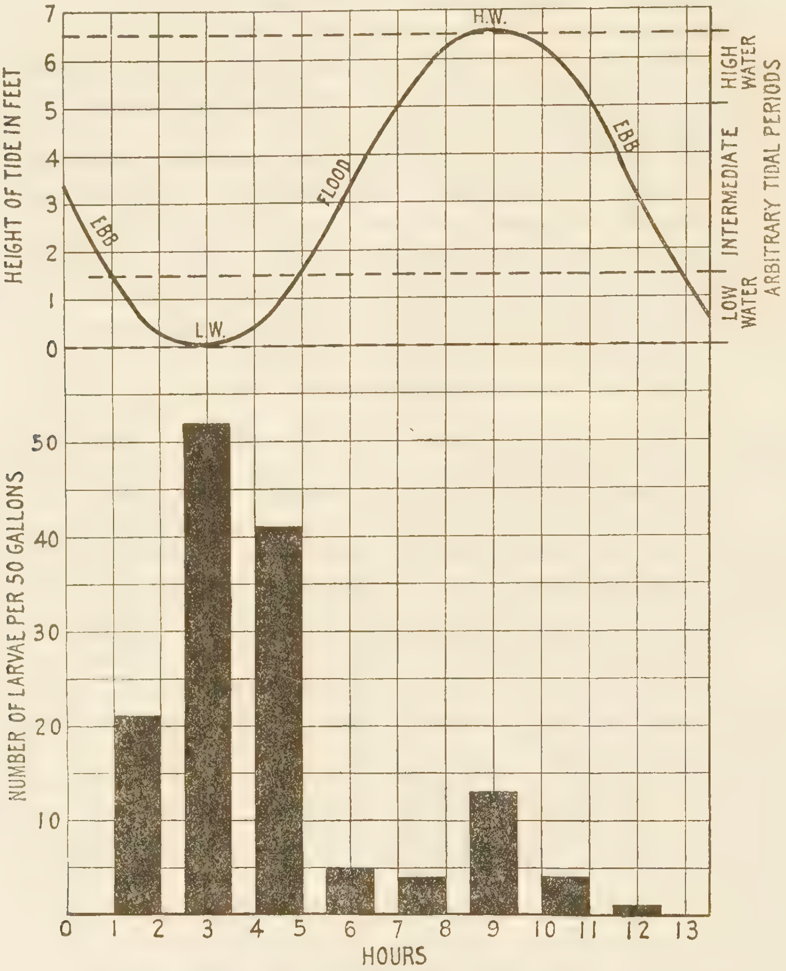

FIGURE 30.—Occurrence of oyster larvæ in plankton in relation to the stage of the tide

The duration of the larval period (from spawning to setting) was found to vary from 13 to 18 days. The variation in the larval periods observed during 1925, 1926, and 1927 is given in the following table.

TABLE 27.—*Duration of larval periods, 1925–1927*

Year	Length of period	Mean temperature of water, ° C.	Remarks
1925	13 days (July 7-20)	20.8	Following light spawning.
1925	16 days (July 13-29)	20.6	Following heavy spawning.
1926	16 days (July 21-Aug. 6)	21.3	Following light spawning.
1926	15 days (Aug. 1-16)	23.2	Following heavy spawning.
1927	18 days (July 1-Aug. 8)	20.0	Do.
Mean	15.6 days	21.2	

In many cases the failure of setting has been attributed to a mortality of larvæ as a result of sudden changes in temperature or salinity and to heavy rainstorms.

In the studies of the physical conditions in Milford Harbor during the periods when larval development was in progress, it has been found that extreme changes in water temperature, ranging from 5° C. to 11.5° C. in 24 hours, or in salinity from 5 to 25 per mille, produced no noticeable decrease in the numbers of larvæ present in the water. During the larval period in 1925 and in 1927, the precipitation was several inches above normal and there was a great amount of fresh water discharged into Milford Harbor. The changes in salinity and the increased velocity of the ebb current following these storms did not kill the larvæ or carry them out of the harbor. The studies at Milford show that the oyster larvæ can withstand wide changes in the temperature and salinity of the water and are not carried away by the tides and currents.

SETTING

The successful collection of oyster seed in any particular region or body of water is dependent upon a knowledge of when setting will occur, where it will be most intensive in relation to the spawning bed or depth of water, and how great the production of spat is likely to be during that season.

In the studies as to the time and distribution of setting in Milford Harbor, various types of spat collectors were used such as tiles, brush, tar paper, and containers filled with oyster, clam, scallop, and mussel shells. The collectors were arranged so as to cover the entire zone from the bottom of the channel to high-water mark—a vertical distance of approximately 17 feet, of which the upper 5 to 9 feet are exposed by the tides.

Setting in Milford Harbor has been observed to occur from July 20 to September 1 but is generally most intensive during August with the peak occurring about the middle of the month. The first early set is extremely light and is followed by a heavy and final set about 8 or 10 days later. For example, in 1925 there were 10 to 15 spat per shell at station No. 3 from the light set on July 20 and from 150 to 250 spat per shell from the heavy set on July 29. The daily examination of the shells showed that the setting period of the majority of the larvæ of a single spawning lasted but two days. In 1926 the heavy set occurred on August 16, which is representative of the average time of setting for this region.

The number of spat produced in the harbor each year varied considerably though the number of spawners was practically the same in each instance. It was found that the intensity of setting could be clearly correlated with the quantity of spawn in the oysters and the early water temperatures. In 1925 when the temperature was above normal and the oysters contained a large amount of spawn, the setting was heaviest, and an average of 15,000 spat were collected per bushel of shells. In 1926 and 1927 we had the other extreme—that is, water temperatures below normal and small amount of spawn in each oyster—with the result that the average number of spat collected per bushel was only 2,000 and 2,500 respectively. Such annual variations in the production of seed on both natural and cultivated oyster beds have long been observed and is largely the result of the fluctuations in the physical condition of the water which have been discussed previously.

The intensity of setting according to depth or in other words the vertical distribution of spat is quite peculiar in Connecticut waters. In Milford Harbor the spat were found to be attached in a zone extending from the bottom of the channel to a point 2 feet above mean low-water mark; while from above this level to high-water mark, a distance of about 5 feet, no setting takes place. In other bodies of water as for example in South Bay, Long Island, setting occurs from the bottom to nearly high-water mark, while in South Carolina and Georgia the set is found chiefly between low and high water marks and not below low-water mark.

On a given area of bottom in Milford Harbor the setting was found to be unevenly distributed and varied in intensity according to the distance from the spawning bed and the depth of water. In the harbor the set was found to occur on such areas as are covered with water when the tide is 2 feet above mean low-water mark, with the exception of a small portion above station No. 1, where setting rarely occurs because of the discharge of fresh water. In 1925 a set of commercial value was found principally within a radius of 300 yards from the spawning bed, the number of spat ranging from 5 or 6 spat per shell on the outside edge to 200 and 300 per shell in the central portion. The spat were most abundant on shells planted over the spawning bed and within approximately 100 yards of its center. The concentration of spat at the 100-yard circle averaged 50 per shell. Though setting occurred practically the same distance upstream or above the bed as it did below it was found to be of slightly greater intensity in the areas lying below or toward Long Island Sound. The horizontal distribution of the set in relation to the spawning bed clearly shows that the oyster larvæ remain close to the place where they were produced.

EXPERIMENTS IN SEED-OYSTER COLLECTION

Various types of spat collectors and materials suitable for the attachment of the oyster larvæ were used during the past four years in Milford Harbor. In 1925 birch brush, glazed tiles, and wire baskets filled with oyster and clam shells were used. In 1926 triangular crates made of lath were filled with shells and set out on the tidal flats in various formations. In 1927 and 1928 wire bags filled with oyster shells were used on a much larger scale and were tested out in Milford Harbor and several other localities in Connecticut. In 1929 experiments were conducted with partition type collectors. In order to simplify matters each summer's experiments will be discussed separately as to the methods employed and results obtained with each type of collector.

In 1929 a new type of collector was developed for the gathering of seed oysters in heavy setting regions. This device consisted of a series of waterproof cardboard partitions, similar to an egg case filler, which was covered with a thin coating of cement. It gave a total collecting surface of approximately 1,000 square inches. In Great South Bay, Long Island, 1,000 of these partitions were planted by the Bluepoints Co., and a similar number were set out by the Connecticut Oyster Farms Co., on the tidal flats in Milford Harbor.

In each region the partitions proved to be very satisfactory and collected from 2,000 to 25,000 spat on a single partition. The advantage of using seed collectors of this design lies in the fact that they are inexpensive and suitable for collecting large numbers of spat which can be separated easily when a few months old. The supply of oyster shells has been steadily decreasing each year and consequently the development of partitions as a practical substitute is significant.

The partitions are superior to shells principally because they can be broken up or separated thus saving the spat after they have grown for two or three months.

For full description of the preparation, use and planting of partitions for the collection of seed oysters the reader is referred to Bureau of Fisheries Document 1076, "Improved Methods for the Collection of Seed Oysters" by H. F. Prytherch.

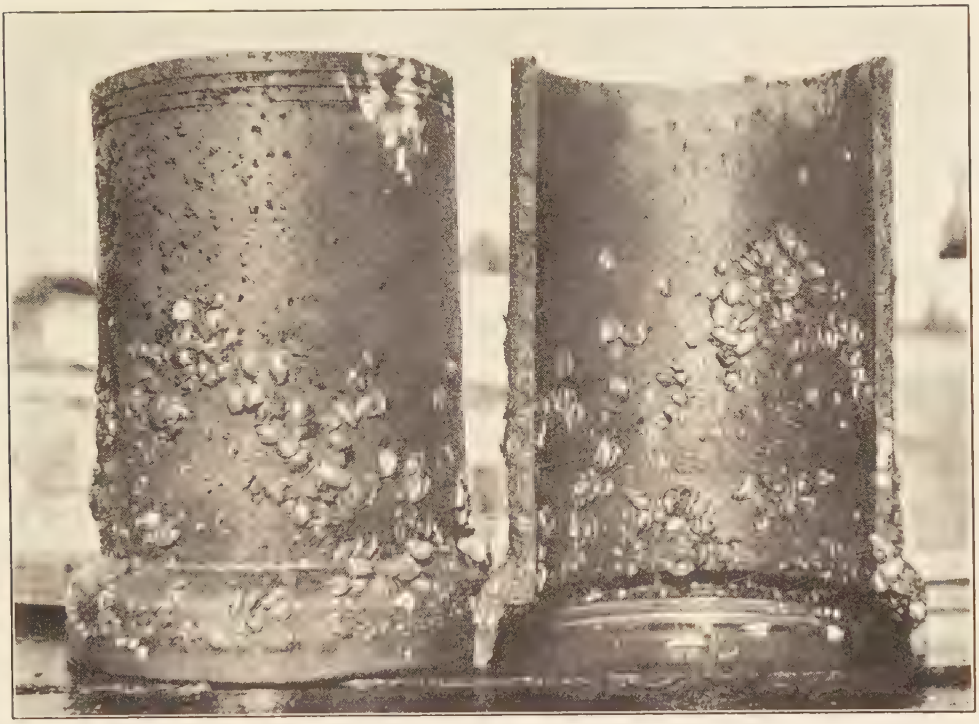

FIGURE 31—Set on tile collectors, Milford Harbor

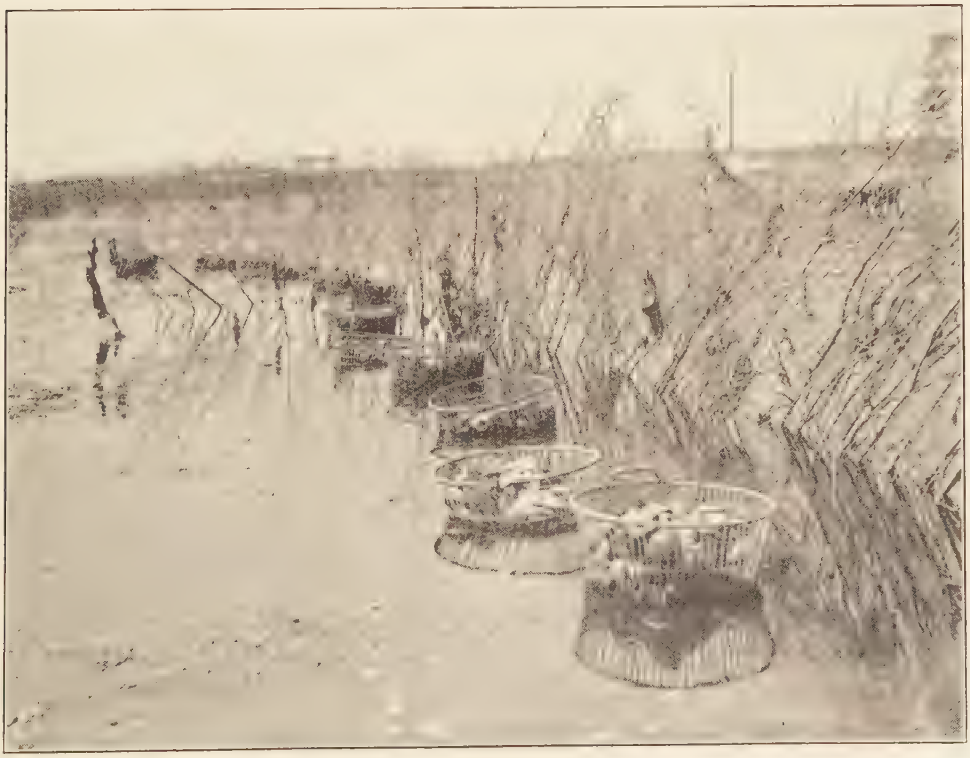

FIGURE 32.—Wire baskets filled with shells, and brush collectors planted at Milford Harbor

EXPERIMENTS IN 1925

In the United States, brush spat collectors have been employed but very little chiefly because of the cheaper and better results generally obtained with oyster shells. Brush, however, is superior to shells in many respects and in certain regions has proved to be a very suitable collector for use on soft mud tidal flats which can not be utilized for any other purpose. In Connecticut the profitable utilization of soft muddy tracts by brush methods is described in the reports of the Connecticut Shellfish Commission for 1882 and 1883. At that time 50 acres of muddy bottoms in the Poquonock River near Groton were planted with white birch brush and yielded as high as 1,000 bushels of oysters per acre. The brush or really young trees which were used, measured around 4 inches at the butt and are said to have yielded as much as 25 bushels on one branch. The average yield, however, is said to have been approximately 5 bushels per branch.

For the experiments in Milford Harbor in 1925, white birch brush or branches were used having a length of approximately 6 feet and a diameter at the butt ranging from 1 to 2 inches. The branches were forced into the soft bottom areas at an angle of about 45° and were arranged in two different formations: (1) In rows at right angles to the direction of the tidal currents and (2) in conical stacks having a diameter at the base of about 8 feet. The branches were set out a few inches apart and were forced into the mud from 6 inches to a foot deep according to their size or length. The planting of the brush was carried on during the first two weeks of July, the operations being confined, of course, to the periods of low water. The areas selected for planting were flat and even and were located at a level corresponding almost exactly with that of mean low-water mark.

Two weeks after the brush planting was completed the setting of the oyster larvæ occurred and was the heaviest observed in this harbor in many years. Studies of the setting (from the standpoint of number per collector, etc.) were not made until the first week in September by which time the spat had attained an average diameter of one-half inch. The number, distribution, and size of the oyster spat on the branches was determined for samples taken from each planting formation and was compared with the results obtained in the baskets of shells and tile collectors which were planted on the same areas.

The number of spat per branch was found to vary in regard to the location of planted area in relation to the spawning bed, the diameter of each branch or twig, and the formation in which each branch was planted. On branches having practically the same diameter at the butt the number of spat ranged from approximately 25 to 300 spat per branch which is quite a low figure in view of the surface area offered for attachment of the oyster larvæ. The branches which were set out below the spawning bed collected nearly twice as many spat as those which were put out upstream or above the bed. Where branches of different size were planted under the same conditions it was found that those having the greatest diameter collected the largest number of spat and that twigs in the same zone having a diameter less than one-fourth inch rarely had spat attached to them. The same general condition was observed in comparing the brush planted in stack formation with that planted in rows. In the stacks the branches were massed closer together and offered greater resistance to the tidal currents with the result that it was easier for greater numbers of larvæ to become attached to branches under these conditions.

In addition to variations in the number of spat per branch it was also found that the distribution of spat showed marked differences according to the direction and velocity of the tidal currents, the height of the collector from the bottom, and the range of tide on the days when setting occurred. The setting of the oyster larvæ in Milford Harbor occurred chiefly at the surface at low slackwater and continued until the flood tide had risen approximately 1½ feet above mean low-water mark. This was clearly shown also by the distribution of the spat on the brush on which they were found to be located on all sides of the main branches in a zone from the bottom to 3 inches above, while above this level they were chiefly on the lee side of each branch and became less numerous as the current and height of water increased. The smaller twigs on the branches offered very little resistance to the currents and consequently no spat were found attached to them, except in a few cases where the twigs were very close to the bottom and in the low slack-water zone.

The experiments in Milford Harbor have shown, however, that brush collectors can rarely be used successfully in northern waters because of the comparatively light setting, slow growth of spat and necessity of transplanting and anchoring the branches in deep water before the first winter. However, satisfactory results have been obtained in southern waters or in regions where setting is heavy and growth of the spat rapid. This has been demonstrated by experiments made in South Carolina and Georgia in which branches 4 to 8 feet long, having a diameter of the butt of about 1-inch were found to be most suitable. (Galtsoff and Luce, 1930.) Where the tidal currents are strong it is best to plant the branches in conical stacks, so that the smaller twigs are closely bunched, to facilitate the attachment of the oyster larvæ by creating eddies. Oak brush was successfully used in Georgia and South Carolina and birch in Connecticut, though for this purpose almost any kind can be used.

The advantages of using brush are:

1. It offers considerable surface area for the attachment of the oyster spat.
2. Oysters growing on the convex surface of the branches are less crowded and have a better shape than those attached to shells.
3. The brush keeps the seed oysters above the bottom, thereby increasing their growth and protecting them to a certain extent from natural enemies.
4. It disintegrates in about a year or is destroyed by shipworms, so that the seed oysters attached to it break apart or can be separated as single specimens.
5. It can be used on mud flats that are useless for the planting of shells.
6. It is a cheap material for the collection of seed oysters and is easily obtained.

A series of experiments was undertaken to demonstrate the suitability of tiles as seed collectors. The tiles used were half-round glazed sewer pipe having a diameter of 12 inches and length of 2 feet. The surface of the tiles was approximately 1,000 square inches and the average number of spat collected per tile was 1,500 from the first set and 4,000 from the second or heaviest set. The setting on the tiles, of course, was not uniform but decreased in intensity from the bottom to the upper setting limit. The setting on tiles planted at low-water mark in vertical positions is shown in Figure 31. The spat, which were attached to them, were allowed to grow until late fall and were then detached from the tiles without the slighest injury and transplanted as single seed oysters.

The third type of seed collector used in 1925 was that suggested by Capt. Charles E. Wheeler, of the Connecticut Oyster Farms Co. It consisted of a round galvanized wire bushel basket which was filled with shells and then set out on the tidal flats. A dozen of these baskets were filled with either oyster, clam, or mussel shells, and collected on the average 15,000 spat per bushel of oyster shells and a few thousand less on the clam and mussel shells. The spat were not uniformly distributed throughout the baskets, but were most numerous on the bottom and outside edges and comparatively scarce on the shells in the middle. By actual count the oyster shells on the top, bottom and sides of the container were each covered with from 25 to 200 spat, those on the next inside layer from 12 to 50, while in the center from 2 to 10 spat were found per shell. The representative distribution of spat in these baskets is shown diagrammatically in Figure 33.

These initial experiments with wire baskets showed that the principle of putting shells into a comparatively open container was an efficient and practical means for collecting seed oysters and worthy of further development in future investigations.

The studies and experiments in 1925 brought out certain fundamental facts which should be summarized briefly as they have a direct bearing upon the development of methods for the production and collection of seed oysters in similar bodies of water. It was found:

1. That inshore areas such as Milford Harbor can be rehabilitated as prolific oyster-producing regions by the establishment of spawning beds.

2. The optimum conditions for successful spawning and setting are to be found in Connecticut primarily in the harbors, bays, and river mouths.

3. Oyster larvæ will remain and set in the vicinity of the spawning bed in spite of adverse tidal currents and river discharge.

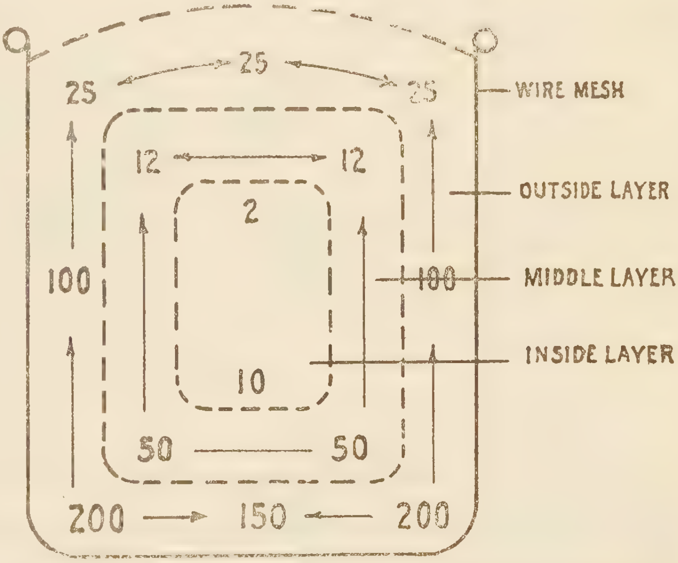

FIGURE 33.—Longitudinal section of wire basket showing distribution of spat. Figures indicate number of spat per shell

4. The attachment of the greater proportion occurs at the time of low slack water and during the first two hours run of flood tide.

5. Setting is most intensive in a definite zone near low-water mark and consequently the spat collecting operations can be concentrated at this level.

6. The planting of suitable spat collectors near the spawning beds is a practicable means of obtaining seed oysters and will be successful almost every year.

EXPERIMENTS IN 1926

The experiments in oyster seed collection during the previous summer indicated that a change in the shape of the shell container should be made that would facilitate the passage of the larvæ amongst the shells and thus produce more uniform setting. For this purpose triangular lath crates were employed, the design and construction of which has been previously described. (See fig. 1.) Three hundred of these crates were planted in various formations on the tidal flats so as to determine their efficiency as seed collectors and the effect of their position and arrangement on the uniformity and intensity of setting within them. The crates were set out during the last two weeks of July, and on August 15 were found to have collected a light set, the counting and distribution of which was not made until the early part of September when the spat were large enough to be easily seen. In analyzing the setting in the collectors, two crates were chosen as representative samples from each group and counts made as to the number of spat per bushel or per shell, and according to the position of the shells in the crate.

In Figure 34 the group formations in which the crates were planted are shown together with the location of the spawning bed and the direction of the tidal currents when setting occurred. The intensity of setting in each group varied somewhat as is shown in Table 28.

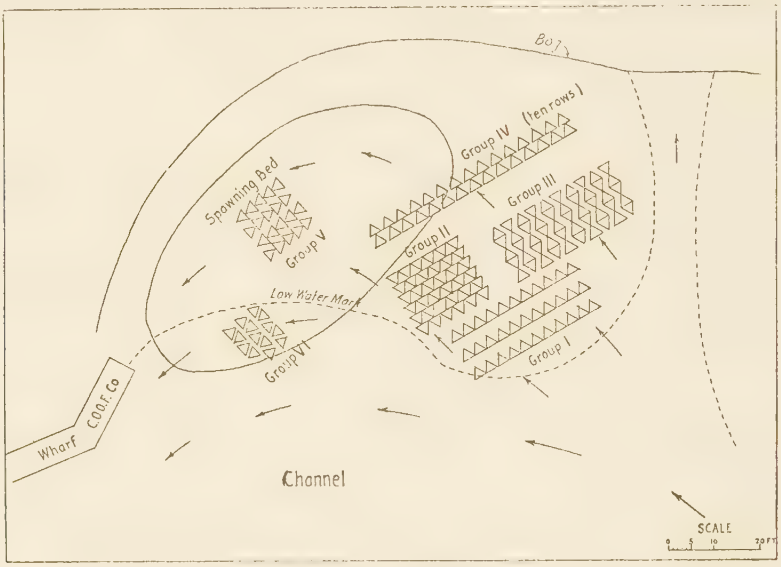

FIGURE 34.—Arrangement of crates on tidal flats, Milford Harbor, 1926

TABLE 28.—*Intensity of setting of oyster spat*

Group number	Crates	Spat per bushel	Total (approximately) spat collected per group	Group number	Crates	Spat per bushel	Total (approximately) spat collected per group
I	50	2,264	226,400	V	20	1,275	51,000
II	30	1,407	84,420	VI	14	1,020	28,560
III	36	2,812	202,464				
IV	150	1,734	520,200	Total			1,113,044

Each crate holds two bushels of oyster shells, so by computation we get an average of 3,710 spat per crate or 1,855 per bushel which corresponded to a light set and was, therefore, of commercial value, The shells which were used averaged 250 to a bushel so that the calculated intensity of setting was approximately 7.4 spat per shell. The setting in the crates was more uniform than in the wire baskets but still was found to vary from 0 to 35 per shell according to their position in the container.

In order to study the distribution of spat in the crates the shells in each crate were divided into three layers—top, middle, and bottom—and counts were made as to the number per shell and the distance each shell was located from the center of the container. The plan used in counting the shells is shown in Figure 35, together with the distribution of spat that was found in three crates planted in Group I. The spat were found to be most abundant on the shells in the corners of the crates while within a radius of 6 inches from the center or from the sides the setting was very light and unsatisfactory. To show this distribution and the typical variation in the number of spat attached per shell, the following record is given for a representative crate taken from Group I. (Table 29.)

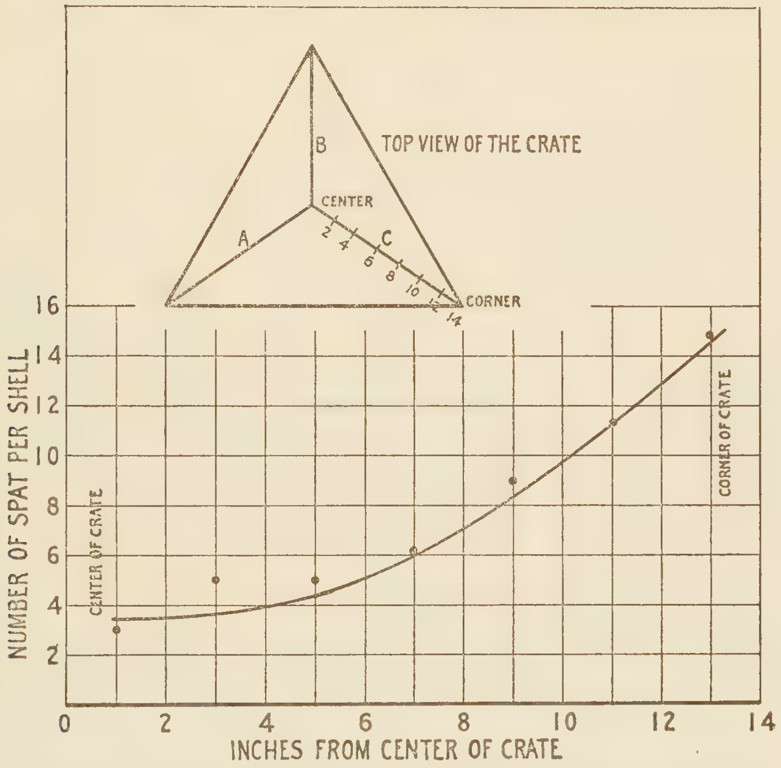

FIGURE 35.—Method of counting and distribution of set in crates. The figures are the averages of three crates in Group 1

TABLE 29.—*Distribution of spat in a crate*

Inches from center	Top layer			Middle layer			Bottom layer		
	Line A	Line B	Line C	Line A	Line B	Line C	Line A	Line B	Line C
14	14	10	26	28	14	15	35	18	16
12	14	20	5	4	13	10	12	14	17
10	16	8	6	1	2	18	19	12	9
8	6	2	14	8	4	4	4	5	7
6	18	7	4	2	1	0	1	3	1
4	3	1	6	1	3	9	0	0	1
2	1	8	3	1	0	0	0	0	0
Total	72	56	64	45	37	56	71	52	51

In the samples taken in each layer we find a total of 192 spat in the top, 138 in the middle, and 174 in the bottom layer which shows fairly even distribution in each zone as a whole. The spat were not more numerous in the bottom layer in the crates because the close fitting of the lath on the bottom and lower side apparently interfered with the penetration and setting of the larvæ. However, if we take the shells in the corners or on the outside edges of the crate we find the usual decrease in setting above low-water mark from 69, at the bottom of the crate, to 57, at the middle or halfway up, and 50 at the top.

A study of the effect of close grouping of crates on the distribution of spat within them was carried out in Group III where the crates were set out within a few inches of each other. (Fig. 34.) The crates on the outside edges of this group collected an average of 1,600 spat per bushel of shells while those in the middle were even more efficient and contained from 2,500 to 3,500 spat on the same quantity of material. An increase in the intensity of setting in the middle portion of the group can be attributed to the decrease in the velocity of the tidal currents and the creation of eddies. In the crates as a whole, setting was invariably found to be most intensive on the lee side of the collectors where the larvæ apparently were able to attach with greater ease.

The setting in the crates placed more than a foot below low-water mark (Group VI) was extremely light as the shells planted there became foul and covered with silt in a very short time while those which are above low-water mark are kept clean by regular exposure to the sun and air. With the conditions existing in Milford Harbor the best results can be obtained by placing spat collectors on areas that lie in a zone extending from 1 foot below to 2½ feet above low-water mark. Such areas are rather limited in northern waters but by using the lath crates or a similar constructed device, supported by legs sufficiently long to hold them above the bottom, it is possible to use the same area for the planting of spawners and for setting out collectors.

EXPERIMENTS IN 1927

In continuation of the work of finding a cheap, efficient, and practical spat collector, wire bags filled with shells, as shown in Figures 2 and 37, were tested out in 1927 in Milford Harbor and Great South Bay, Long Island. Six hundred collectors of this type were planted on the flats in Milford Harbor and in addition 300 bushels of shells were put out in a pyramidal wire collector having a wood base 12 inches square. This latter type of container was designed by Capt. Charles E. Wheeler of the Connecticut Oyster Farms Co., and proved to be suitable for the planting of shells on soft mud bottoms. One thousand bushels of oyster shells were scattered over the bottom between the bags in order to make a comparison between this usual method of seed collection and the wire bags.

Because the spring and early summer water temperature in 1927 were below normal, the oysters developed only a small quantity of spawn and were not fully ripened until near the middle of July. Spawning occurred on July 24 and the setting of the larvæ reached its peak on August 8. The setting was slightly heavier than in 1926 averaging 2,450 spat per bushel in the wire bags and 1,500 spat in the pyramidal type of collectors. The number of spat collected in the bags was found to vary from approximately 1,500 to 3,500 per bushel, according to the location in which they were planted in the harbor, or to their position in relation to low-water mark.

The distribution of spat within the bags was very satisfactory, the setting being fairly uniform and occurring on over 95 per cent of the shells. In making the counts

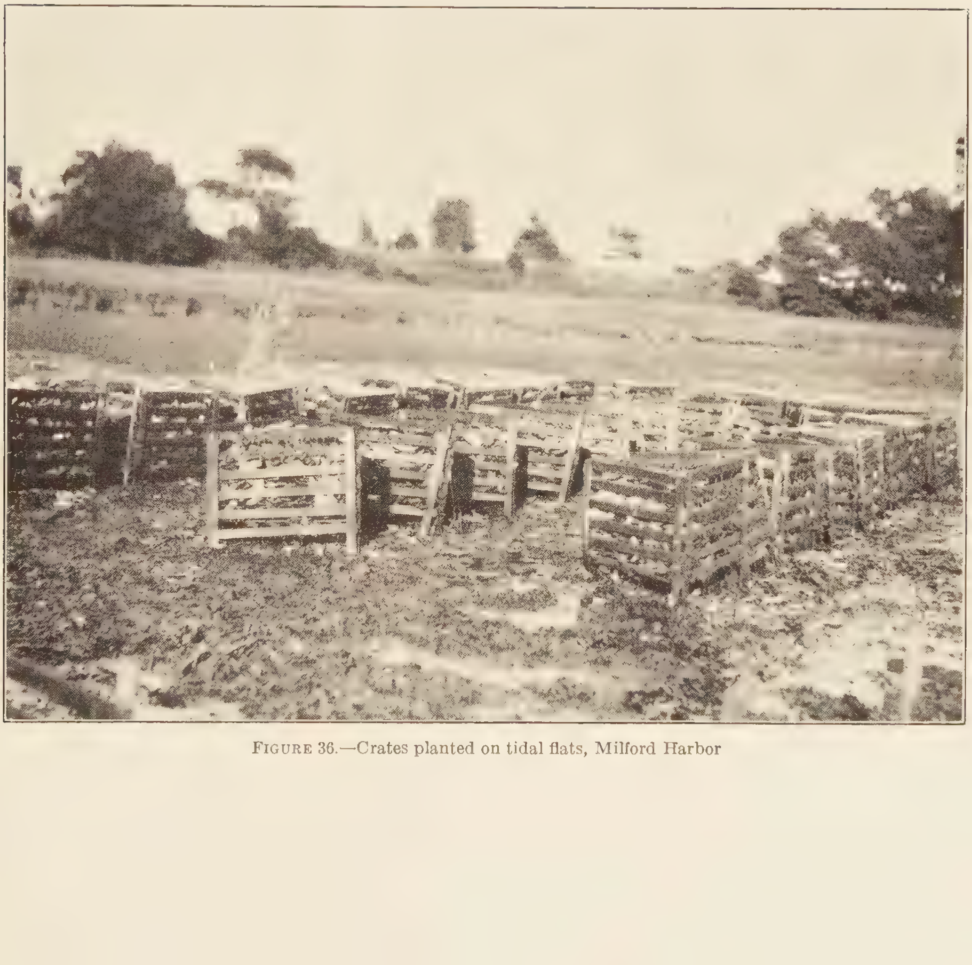

FIGURE 36.—Crates planted on tidal flats, Milford Harbor

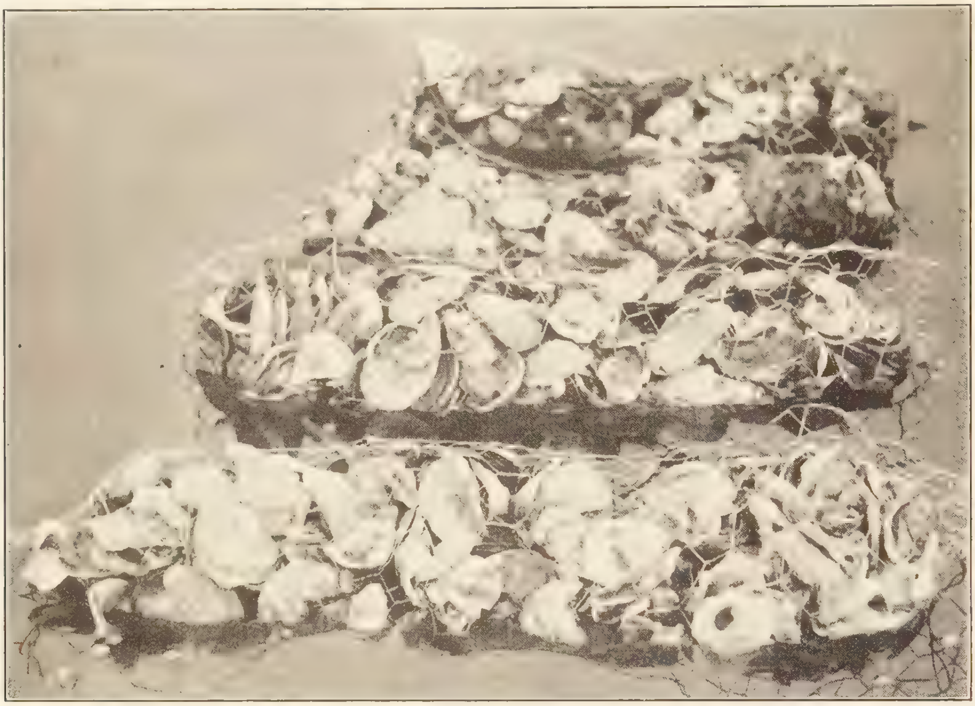

Figure 37.—Wire bag collectors planted on tidal flat, Milford Harbor

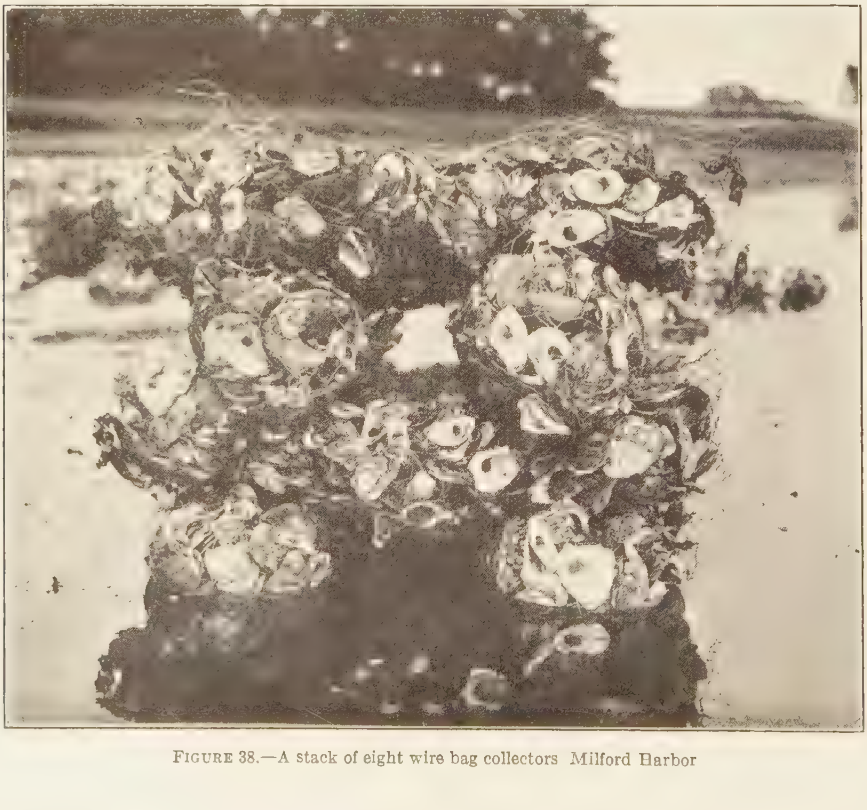

Figure 38.—A stack of eight wire bag collectors Milford Harbor

a representative sample of one-half bushel of shells was taken from each bag and the number of spat per shell determined.

In Figure 39 the frequency distribution of spat on the shells is shown for three different bags in which the intensity of setting varied from 1,900 to 3,150 spat per collector. The bags were all planted under practically uniform depth and current conditions but were located at different positions in relation to the spawning bed.

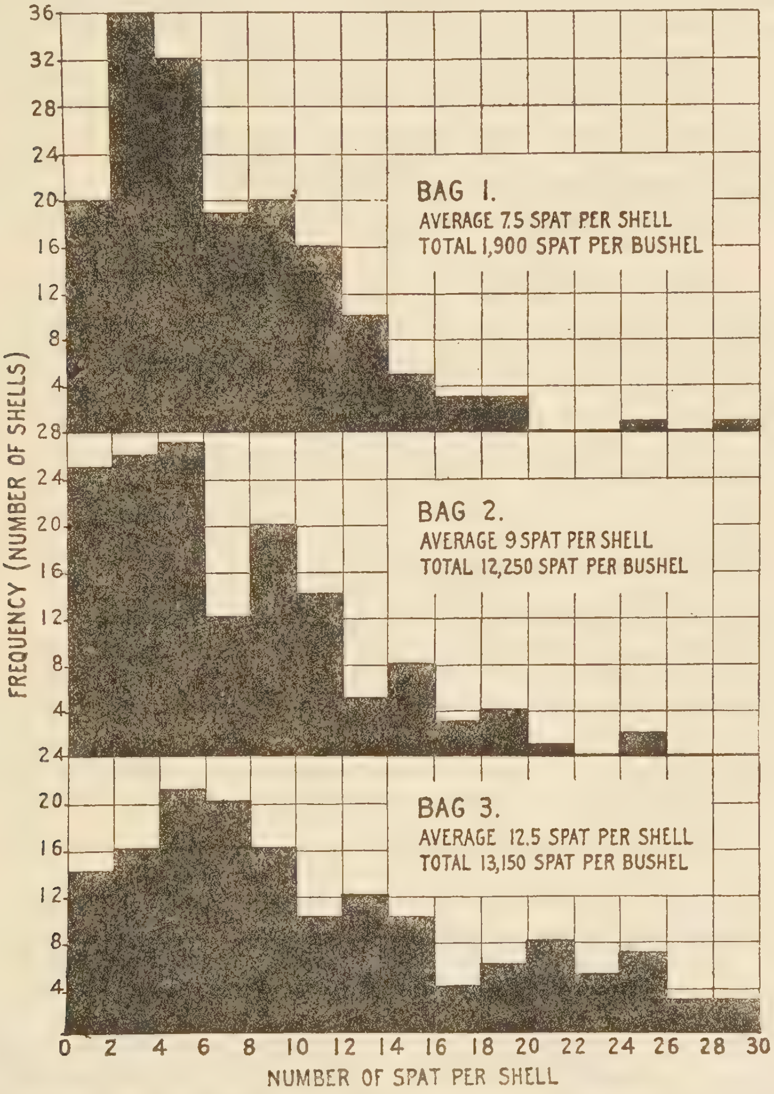

FIGURE 39.—Frequency distribution of spat on shells from wire bag collectors, Milford Harbor, 1927

Bag No. 1 was at the upper end of the bed, No. 2 in about the middle, and No. 3 just below the southern or lower limit of the bed where setting was the heaviest. The figure shows clearly that with an increase in the intensity of setting there is a greater uniformity of distribution of spat on the shells. In bags Nos. 1 and 2, where the setting was comparatively light, it was found that 66.5 per cent and 70 per cent of the shells, respectively, had collected a satisfactory set or more than 4 spat per shell. In bag No. 3 only two blank shells were found and 81 per cent of the shells were covered with sufficient numbers of spat. The variation in the number of spat per shell is really slight if we consider the different sizes of shells and the large number of positions in which they may become arranged in the wire container.

One of the advantages of the wire bags is that they can be stacked or piled up in tiers and thus increase greatly the amount of shells that could be planted on a given area. The shell bags were planted in tiers at several different points in the harbor and counts made as to the number of spat that were attached in the bags at each particular level. A photograph of one of the stacks is shown in Figure 38. The intensity of setting in each tier is shown in Figure 40 for two representative stacks, one of which was located at the upper end of the spawning bed and the other at the lower end. The figures given in this diagram are rounded off to the nearest 250 unit and show clearly how setting is of greatest intensity near the bottom or at low-water level and decreases gradually in the zone above. In each of these tiers there were two bags or eight in all in each stack which gives us a total collection of 7,500 spat for the upper stack and 18,000 for the lower. The area of bottom covered by one stack is approximately one square yard which gives us a unit for comparing this method of seed collection with the usual practice of scattering from 500 to 1,000

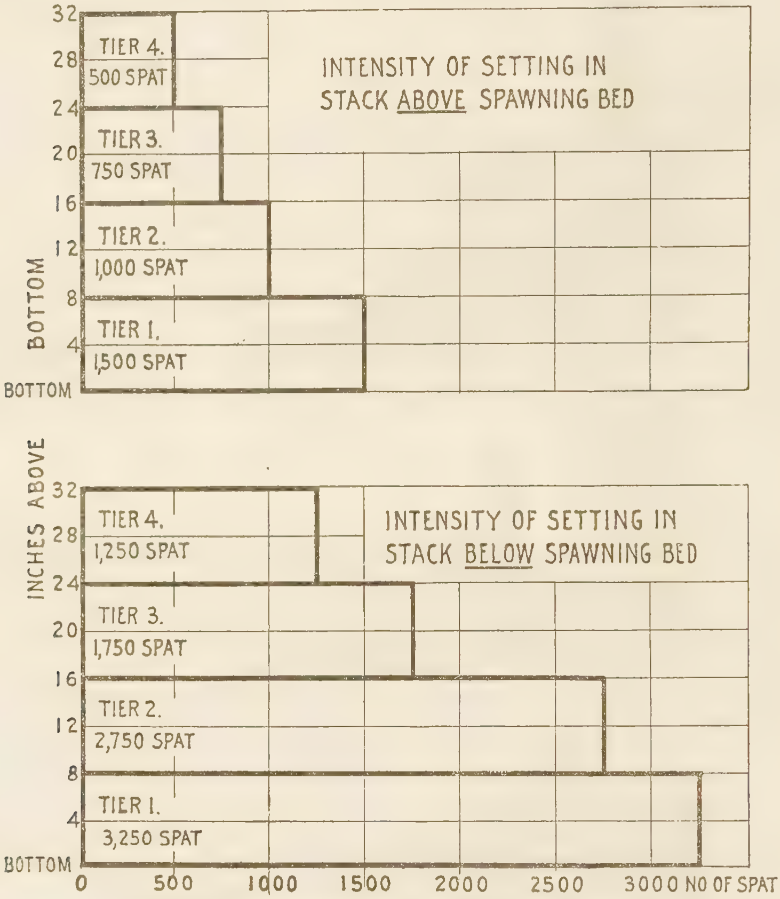

FIGURE 40.—Intensity of setting in stacks of wire-bag collectors

bushels of shells per acre. By the former method there is an efficient distribution of 8 bushels of shells per square yard (when 4 tiers are used) while by the latter, only 0.1 or 0.2 of a bushel are planted on the same area. Several samples of the scattered shells from the surrounding bottom were collected and counted and on these the setting ranged from approximately 1,500 to 2,000 spat per bushel. On one square yard of bottom in the best setting region in the harbor a production of 18,000 seed oysters was obtained in a single stack while on the scattered shells only 400 seed oysters were collected. The question naturally arises as to what the production would be on the scattered shells if they were planted more densely. This was tested out at a concentration of 2 bushels of shells per square yard in which the setting was found to be extremely poor and at best was less than 1,000 spat per bushel while in the wire bags only a few feet away over 3,000 spat were found on the same amount of shells. In the dense planting of shells, setting occurred almost entirely in the upper or exposed layer where the shells were much cleaner than those underneath.

The number of shell bags that can be planted successfully in a single stack will vary somewhat in each locality according to the depth of water, tidal conditions, and especially the zone in which setting takes place. Similar experiments were made in cooperation with the Bluepoints Co., at Great South Bay, Long Island, where the zone of setting extends from the bottom to nearly high-water mark. The bags were arranged on the deck of the oyster boat in tiers of six and the entire stack lowered over the side by means of the galvanized wires that bound them together at the corners. Twelve such stacks were set out in water 8 to 10 feet deep, and practically every shell caught a certain number of spat, most of them being well covered with from 50 to 100 per shell. The setting in the bags was decidedly heavier than it was on the shells scattered over the bottom and likewise the growth of the spat was much more rapid in the elevated collectors. In South Bay the setting is oftentimes extremely heavy (1,000 to 2,000 spat per shell) but for some unknown reason the spat invariably die during such prolific years unless they are elevated a few inches above the bottom. Therefore, the successful use of shell bags in this body of water is significant as it demonstrates not only a practical method of fully utilizing the heavy sets that occur but especially a means of keeping the spat alive.

EXPERIMENTS IN 1928

In 1928 the wire-bag method of seed-oyster collection was put into practice on a small commercial scale in four different harbor areas in Connecticut. The plantings were made in Milford Harbor by the Connecticut Oyster Farms Co., in New Haven and East Haven Harbors by F. Mansfield Oyster Co., in Branford Harbor by E. Ball & Co. In each locality the plantings were successful; the production of seed oysters ranging from 5,000 to 25,000 spat per bag. In Milford Harbor, where there were plenty of spawners, the setting was heaviest and varied from 9,000 spat per bushel, or an average of 30 per shell to over 25,000 per bushel or 85 spat per shell—the most intensive setting occurring in the bags that were planted just above low-water mark. The shells on the bottom and outer layer of the bag were covered with from 47 to 195 spat per shell while those further inside averaged approximately 25 per shell. Complete counts of the shells in many of the bags showed that the attachment of the larvæ within them had been exceedingly uniform and that less than 1 per cent of the shells had failed to collect spat. A summary of results obtained with wire-bag collectors in various localities of Connecticut shores and in Great South Bay, N. Y., is given in Table 32.

TABLE 32.—*Summary of results obtained with the wire-bag type of seed-oyster collector*

Observations	1927		1928	
	Milford Harbor	Great South Bay	Milford Harbor	Other Connecticut harbors
Average number of spat per bag	2, 450	18, 000	15, 000	15, 000–20, 000
Maximum number of spat per bag	3, 500	22, 000	26, 000	25, 000
Minimum number of spat per bag	1, 500	7, 500	9, 000	5, 000
Average number of spat per shell	9	75	60	70
Maximum number of spat per shell	50	150	85	100
Per cent of shells covered with spat	95	90	99	90–98

V. CONCLUSIONS

By P. S. GALTSOFF and H. F. PRYTHERCH

Observations and experiments carried out by the authors from 1925 to 1928 along the coast of Cape Cod and in Long Island Sound indicate that there exist many thousands of acres of formerly productive bottoms which at present are depleted to such an extent that it is difficult to find a few live oysters on them. These areas can be rehabilitated by the establishment of spawning grounds and by employment of spat collectors for obtaining seed oysters. Since suitable bottoms for collecting the set are limited, it is necessary to employ such devices as crates, shell bags, or brush in order to present a greater area of surface for the attachment of the oyster larvæ.

It has been demonstrated that by means of the bags (3 feet long, 1 foot in diameter) made of poultry wire, filled with oyster shells, and stacked in various formations the number of seed oysters collected per a given area of bottom can be materially increased. In Wareham River from 15 to 30 times as many seed oysters were collected on a given area as by ordinary methods. In Onset Bay the number of spat, per a unit of area, in one layer of horizontally laid bags was 4 times greater than on the adjacent bar. Since it is possible to put 3 or 4 layers of bags over 1 square yard the productivity of seed oysters in that bay can be increased from 12 to 16 times as compared with the present method of planting. In the experiments at Milford Harbor 45 times as many seed oysters per given area were obtained in the stocks of bags as on loose shells scattered over the bottom.

A success with the wire-bag collectors depends on several conditions. There must be sufficient number of spawners (at least 500 bushels to an acre) in the vicinity of the collectors. The temperature of the water must be above 20° C. because no spawning takes place below that temperature. The surface of shells or other cultch must be clean since slime or overgrowth of algæ prevent the attachment of the larvæ. The bags must be planted in the zone of heaviest setting which could be determined either by preliminary experiments or by a careful examination of piles, wharves, and other underwater structures or objects.

Crates and wire-bag collectors can be successfully used either on soft bottoms or on sandy and shifting bars where ordinary planting of shells is impossible.

Though the production of seed oysters varies somewhat from year to year, the relative intensity of setting that will occur each season can be estimated a month or more in advance from the examination of the gonad development of the oysters and analysis of the daily temperature records. A full description of this method and its application can be found in the paper of Prytherch (1929).

The experiments with the shell bags carried out in several localities described in this paper show clearly that this method of seed collection can be successfully applied on a commercial scale in the inshore areas of North Atlantic States.

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COMMERCIAL SNAPPERS (LUTIANIDAE) OF THE GULF OF MEXICO[1]

By Isaac Ginsburg, *Assistant Aquatic Biologist*

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INTRODUCTION

There has recently come to the attention of the American fishery industry some species of snappers which have a prevailing red color, are taken in deep water, and have a close resemblance to the common and valuable red snapper, *Lutianus blackfordii.* These snappers, however, are not of the same excellence as the common red snapper, although it should be possible to find a market for them when sold under their own distinctive name. It is desirable, therefore, to point out the specific characters by which they may be distinguished. Current descriptions are based chiefly on young individuals, whereas there is a considerable difference in appearance between the young and the large market fish. Therefore the large fish are described and figured below, and it is shown how they may be distinguished from the more valuable common red snapper. Some problems connected with the further study of the snappers are indicated.

LUTIANUS VIVANUS

Synonyms of common names.—Silk snapper (St. Thomas, West Indies). Yellowtail (Pensacola, Fla.). Pargo de lo alto (Cuba). Vivanet, Vivanenux (Martinique). Chierkie boca blanca (Curacao).

Formulæ.—D. X 14. A. III 8. Scales 72 to 73. Gill rakers 11 and 6 rudiments.

Description.—Upper profile rather gibbous in front, markedly ascending to the nape, where it makes a rather narrow curve horizontally, thence descending in a broad gentle curve to the caudal peduncle; lower profile of head gently descending, a broad very shallow curve from throat to anal fin.

Depth at origin of ventrals 2.95; head (measured to soft posterior apex of opercle) 2.82 in length without caudal. Snout (measured to soft anterior margin of eye) medium, 2.60; maxillary somewhat shorter than snout, 2.69 in head. Eye (measured horizontally by placing points of caliper between soft margins) rather large, 5.27 in head, 2.02 in snout, and 1.96 in maxillary; least depth of caudal peduncle 3.45 in head.

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[1] Submitted for publication Apr. 23, 1930.

Maxillary nearly reaching under anterior margin of eye; articulation of mandible nearly under anterior margin of pupil; margin of preopercle with a broad shallow emargination above lower angle, its entire edge finely denticulate, the spinules below the emargination coarser; knob on interopercle but faintly indicated.

Teeth in upper jaw with an outer enlarged row, 2 canines in front markedly larger than others with a pair of smaller canines between, one on either side of symphysis; the teeth behind enlarged ones gradually growing smaller posteriorly; a narrow band of villiform teeth behind outer enlarged row extending to angle of mouth and interrupted at symphysis. Lower jaw similarly with an outer row of enlarged teeth, the hindmost two conspicuously larger, the others subequal, the band of villiform teeth extending but a short distance on either side of symphysis. Teeth on vomer in a somewhat anchor-shaped patch, the backward extension on the midline of moderate length. Teeth on tongue in two patches, a large elongate patch on middle and a much smaller oblong patch in front.

Lower limb of first gill arch with 11 gill rakers and 6 tubercles in front, the gill rakers gradually passing into the tubercules; upper limb with 2 graduated gill rakers near the angle and 5 short stumpy subequal ones above, the latter sharply separable from the lower two. Same number of gill rakers on both sides.

Exposed portions of scales on sides, higher in front, the scales behind head at about level of posterior tip of opercle, being about 1¼ times as high as those over anal fin. Modified scales of lateral line not overlapping, numbering 51 to base of caudal; 72 vertically oblique rows over lateral line and 62 below (counting the rows running upward and backward); 9 in a row from origin of dorsal and 15 from origin of anal to lateral line; 7 rows on cheek; scales on cheek continued upward behind the eye to a level of upper margin of eye; behind the eye and slightly above a level through its upper margin there is present an isolated horizontal row of 7 small nonimbricate scales (may be called temporal scales).

Origin of dorsal over upper angle of base of pectoral distance of dorsal origin from tip of snout 2.51, and its base 1.95 in length without caudal, soft part angulated, ninth ray longest, 2.58 in head; pectoral strongly falcate, 1.13 in head, its tip reaching a vertical through vent; length of ventral 1.59 in head, its origin but slightly behind lower angle of base of pectoral, its tip falling short of anus by a distance nearly equal to vertical diameter of eye; origin of anal under base of third soft dorsal ray, end of its base under tenth dorsal ray, length of base 2.6 in head, the hind margin rather falcate, third soft ray longest, 2.24 in head, second spine 4 and third 3.58 in head; upper caudal lobe a little longer than lower, middle rays 1.81 in longest upper rays.

Color in fresh condition (*iced specimen*).—Rose red, darkest at back and gradually shading off to a lighter reddish silvery tint on belly. Centers of most scales on upper half usually greenish, frequently whitish, giving the fish somewhat of a streaked appearance. Caudal fin yellowish, washed with pink, with a marginal band of lighter yellow. Dorsal red margined and irregularly washed with yellow shades, especially on soft part. Anal similar to soft dorsal. Ventral pinkish washed with yellow. Pectoral light yellowish in anterior half becoming hyaline posteriorly, its base deep red. Pupil dark blue. Iris bright yellow. No dark lateral spot.

After being preserved in alcohol the bright red and yellow colors nearly all disappeared, while the black pigments became more prominent. The iris remained golden yellow, but some shadings of black pigment have appeared. A little diffuse black pigment at the base of the pectoral and a very narrow marginal streak of black on the posterior edge of the caudal became evident, although not seen in the fresh specimen. The longitudinal rows of small spot in the centers of the scales are present but have changed from greenish to brownish.

The foregoing description was drawn from a specimen 52 centimeters in total length. Another specimen of 63 centimeters received at the same time showed the following differences: The eye when fresh was orange suffused with red. The body is markedly deeper. The backward extension of the vomerine teeth is somewhat longer. The anterior patch of teeth on the tongue is much better developed, being subquadrate and about as wide as the posterior patch. The origin of the dorsal is further backward, being slightly behind origin of ventrals. The temporal band of scales is more oblique, nearly parallel to the nuchal band; the scales are larger, imbricate, and have a second incomplete row. These differences are slight and are most probably due to variation in the age of the specimens and to individual variability. To definitely determine their significance would require many specimens, and it is manifestly impractical to preserve great numbers of these large fish. These differences, therefore, are put on record here and their value must await being tested by field observations of the commercial catch. The proportional measurements of this specimen are as follows: Head 2.92, depth 2.75, antedorsal distance 2.56, and base of dorsal fin 1.92 in length without caudal, snout 2.55, maxillary 2.63, eye 5.55, longest dorsal spine (fourth) 2.57, pectoral 1.08, ventral 1.44, base of anal 2.51, second anal spine 3.8, third 3.6, longest soft anal ray (third) 2.26, caudal peduncle 3.16 in head. The color when fresh was of a deeper red all over, and the yellow shades on the fins and eye were not as pronounced. The caudal may best be described as red, washed with yellow shades. Iris orange color tinged with red. Base of pectoral shaded with dusky.

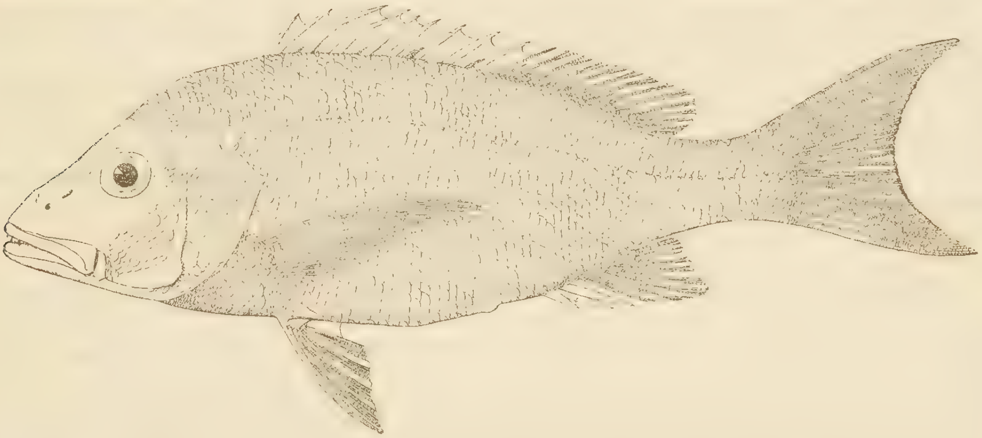

FIGURE 1.—*Lutianus vivanus.* From a specimen 56 centimeters (22 inches) total length, taken at the Cámpeche Banks off the coast of Yucatan, in the Gulf of Mexico. Drawn by Miss Louella E. Cable

ECONOMIC IMPORTANCE

This species is a common market fish in the West Indies, where it is said to be highly esteemed. In the Caribbean Sea it seems to replace to a large extent the red snapper of the Gulf of Mexico. In the absence of any definite statistics it is not possible to estimate its exact economic importance or its relative importance to the other deep-water snappers. It is said to reach a weight of 40 pounds.

Students of the fishery industry of the United States have hitherto given little consideration to this fish. Recently, however, the present species appears to have entered the catch of the American snapper fishermen to a considerable extent. In a recent number of the Fishing Gazette (New York, vol. 47, No. 2, p. 37, February, 1930), there is an article regarding a "yellowtail" snapper which states as follows:

> PENSACOLA, FLA., January 20.—During the last few months a great many of the fishing vessels from Pensacola have been fishing in deep water, where they have been catching the species of the red snapper known locally as the yellowtail. These fish are caught in deep water only and on being brought to the surface present a very attractive appearance, although they are several shades lighter in color than the red snapper and have a yellow tail and a bright yellow eye.
>
> For some unknown reason the yellowtail will not keep for any length of time, and those that have been on ice only a short time give off a very disagreeable odor when cleaned and cooked. The bringing in of these fish to Pensacola has caused a good deal of complaint from the trade, and in all cases the customers were either made an allowance on the shipment or reshipped real red snappers.

> The fishermen were given instructions to the effect that nothing over half of their catch could be yellowtails, but with the increased catches these instructions were changed to *no yellowtails will be accepted.* From now on only the real red snapper will be shipped from Pensacola.

The Bureau of Fisheries, acting on the above report, has received, through the courtesy of the Warren Fish Co. of Pensacola, two specimens of the "yellowtail" referred to above, which form the basis of the foregoing description. In view of the fact that what appears to be the same species is said to be a highly esteemed market fish in the West Indies, it seems possible to find a market for this fish in this country when sold under its own name, instead of lumping it with the red snapper.

J. F. Taylor, president of the Warren Fish Co., in a letter dated March 14, 1930, accompanying the shipment, has made some interesting remarks regarding the economics of this fish, as follows:

> Agreeable to your request we are sending you two different specimens of yellowtails and in addition are sending a third specimen which the fishermen have dubbed hambone [*L. buccanella*]. This latter fish is comparatively rare and is taken only on rock bottom.
>
> The yellowtails are very plentiful and are taken, generally, from mud bottom. Whether they take mud into their stomachs when feeding or whether there is some other cause that makes them objectionable we are not certain, but we do know that our trade decline to handle them, claiming that they do not keep well, also that they give off a very strong odor while cooking, and that a great many complaints are received to the effect that the fish "curl"[2] while cooking.

RELATIONSHIP

This species is very similar in general appearance and coloration to *L. blackfordii* and *L. campechanus,* so that the three may be readily confused. The three species form a group of closely related snappers, having a close resemblance to one another, being of a predominating red color, and found chiefly in deep water. They may be distinguished by the following analysis of their characters. The present species is especially close to *campechanus* from which it may be separated with difficulty, although when two specimens were placed side by side it is evident that they represent two distinct species.

a. Anal fin with 8 soft rays. Scales in 69 to 73 oblique rows above lateral line. Lower limb of first gill arch with 15 to 17 gill rakers, including the 5 or 6 rudiments.[3] Scales on anterior part of body below lateral line not much larger than posterior scales. Eye in large specimens comparatively large, approximately 2 in snout.

b. Snout conspicuously short and compact, rather shorter than maxillary. Head shorter, 2.94 (in individual 50 centimeters long) to 3.11 (in 72.5-centimeter fish). Scales above lateral line markedly smaller than those below, 69 to 71 oblique rows above and 53 to 57 below. Gill rakers on lower limb of first gill arch 15, including 5 rudiments. Caudal peduncle deeper, 3.00 (in 50-centimeter fish) to 2.9 (in 72.5-centimeter fish). Anal spines comparatively more slender. Posterior edge of preopercle making a right or slightly acute angle with the lower edge. Iris red in life; yellow shades very sparse or absent________*L. campechanus*

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[2] In connection with the last statement of Mr. Taylor, it is interesting to note that Poey in his description of (Mesoprion) *Lutianus rosaceus* (Ann. Lyc. Nat. Hist. New York, vol. 9, p. 318, 1870) states with respect to that species: "The flesh is hard to cook; it swells, twists, and remains hard, though its flavor is not bad." *L. rosaceus* is also said to have "the caudal yellowish toward the margin." This latter species, in view of the characters of its teeth, has been doubtfully regarded to be the same as the muttonfish. However, the remarkable coincidence in the character of the meat, which one states that it "twists" and another that it "curls," is significant. Does the name *L. rosaceus* represent a species distinct from the muttonfish, and is the "yellowtail" of Pensacola partly this species? This is a problem which should receive attention in future studies of the snappers of the Gulf. The two specimens sent by Mr. Taylor have the teeth on the vomer and tongue like those described for *L. vivanus.* Very little is really known regarding the deep-water snappers, although of so much economic importance. One great drawback to a comprehensive study of these fishes is their large size. Descriptions are based, therefore, on too few preserved examples, or on market fish where conditions are not favorable for close comparative study.

[3] The number of gill rakers in the American species of *Lutianus* generally shows remarkably little intraspecific variation if the "rudiments" are included in the count. These so-called rudiments in the very young are really very short gill rakers; and, while they are rather abruptly shorter than the posterior gill rakers, no consistent line may be drawn between them. As the fish grows older the anterior short ones are gradually reduced and become "rudiments" or "tubercles." Since this process is gradual up until a certain length, conflicting results will be obtained when the rudiments are not included in the count.

bb. Snout a little longer than maxillary. Head 2.82 (in 56-centimeter fish) to 2.92 (in 65-centimeter individual). The difference in the scales above and below the lateral line not so great, 72 to 73 oblique rows above and 62 to 65 below. Gill rakers on lower limb of first arch 17, including 5 rudiments. Caudal peduncle more slender, 3.45 (in 56-centimeter fish) to 3.16 (in 65-centimeter fish), in head. Anal spines notably stouter. Posterior edge of preopercle making an obtuse angle with lower edge. Iris bright yellow in life (becoming reddish orange in older fish); caudal fin more or less extensively diffused with yellow shades. *L. vivanus*

aa. Anal fin with 9 soft rays. Scales in 58 to 63 rows above lateral line, 47 to 48 below. Lower limb of first gill arch with 14 gill rakers, including 5 rudiments. Scales on anterior part of the body below lateral line strikingly larger than those on posterior part of body. Eye in large specimens comparatively smaller, about 2¾ in snout. Snout slightly longer than maxillary. Iris red in life; yellow shades on caudal not extensively developed----*L. blackfordii*

The above analysis partly refers only to large specimens, 2 *blackfordii* 77.5 and 79 centimeters, 2 *vivanus* 56 and 63 centimeters, and 2 *campechanus* 72.5 and 50 centimeters. Smaller specimens of this genus differ markedly in their proportional measurements, the principal difference being in the strikingly larger mouth, comparatively, the longer maxillary, the larger eye, and the shorter snout in the young. These characters while of specific significance, are consequently of value only when specimens of approximately like size are compared. Also in the young, the pectoral and ventral fins extend further back in relation to the vent and anal origin, and the spines are relatively longer. The relatively large size of the scales on the anterior part of the side is strikingly evident in a specimen of *blackfordii* of 155 millimeters which has been examined.

NOMENCLATURE AND SYNONYMY

This species is evidently the same as is currently designated by writers as *L. vivanus*, and accepted usage and synonymy have been followed in this paper. One discrepancy, however, may be pointed out. Cuvier and Valenciennes describe 13 dorsal rays. The same number was found by Jordan, who reexamined the types. Also, Gunther, who had four specimens from Jamaica and Bahia records the same number of dorsal rays. Now, since the number of dorsal rays in the species of Lutianus generally show but a small degree of variation, these recorded numbers are significant; and, while they may be due to errors in counting or to individual variation, yet it is well to bear them in mind in any future investigation of the snappers. With regard to *profundus*, which has generally been placed in the synonymy of this species, Poey states that the black lateral spot begins to disappear in individuals over 10 pounds. However, he later made another statement (in Fauna Puerto Riquena by Gundlach, p. 321) that he saw the lateral spot only once in a specimen as large as 160 millimeters, which by implication, corrects his previous statement regarding the lateral spot. Poey, in his description of *profundus*, does not mention any yellow shades on the tail, but on the contrary states "le carmin devient plus vif a l' extremite de la caudale." This may be due, however, to individual variation.

The synonymy of the three species is evidently inextricably scrambled. To straighten this out satisfactorily would require a reexamination of the widely scattered material on which the records are based, a task which is difficult to perform. Some of the records are also based on examination of fish in markets, and, consequently, are impossible of verification, while others no doubt include more than one species. However, it would help toward an understanding of the species, if the synonymy were segregated, in so far as that may be done by considering published descriptions solely.

I have attempted below the thankless task of segregating the synonymy of the three species. This should prove useful, but it must be taken with a grain of salt. Cope's *torridus* has been placed in the synonymy of this species, following the action of Jordon and Swain. It may be pointed out, however, that Cope's fish had a relatively deeper body considering its size, a longer pectoral fin, and the author also mentions a brown stripe under the dorsal fin, characters which would suggest *buccanella* a description of which is given below.

GEOGRAPHICAL DISTRIBUTION AND HABITAT

Since published records are doubtful, no final comprehensive statement may be made now with assurance in regard to the range of the separate species. It seems evident that their ranges overlap. *L. vivanus* and *L. campechanus* are more southern fish, while *blackfordii* ranges further northward; but all three probably occur together in the southern part of the Gulf of Mexico, in the Caribbean Sea, and possibly as far south as Brazil. They seem also to differ with respect to their habitat. *L. blackfordii* occurs on rocky bottom, and the great bulk of the catch is probably obtained in water up to 50 fathoms in depth, while *vivanus* lives on muddy bottoms and generally ranges in deeper water. *L. campechanus* may also be expected to occur in deeper water than *blackfordii.* The specimens here described were obtained by the fishermen out of Pensacola, in the Gulf of Mexico, on the southern edge of the Campeachy Banks in about 73 fathoms.

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Lutjanus vivanus, Metzlaar, Rap. Kolonie Curacao, p. 64, 1919. (Curacao; St. Martin; St. Eustatius.)
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LUTIANUS BLACKFORDII

COMMERCIAL IMPORTANCE

This is the common red snapper which is sold in the markets of this country. It is obtained largely in the Gulf of Mexico and marketed chiefly through the port of Pensacola. Small quantities are also taken by the fishermen on the east coast of Florida and off Georgia. Almost the entire catch is obtained with hook and line in deep water. The red snapper is one of the important food fishes of this country. During 1927, which probably represents an average year, it was marketed to the extent of about 12,000,000 pounds, which brought $1,000,000 to the fishermen. Among the commercial food fish of the Gulf coast, excluding mollusks and crustaceans and the menhaden, the red snapper is second in point of quantity obtained, being exceeded only by the mullet, while its value to the fishermen is not much less than that of the mullet, although about 2½ times as much of this latter fish is marketed. Aside from its monetary value, the red snapper is of importance as a natural food resource because of the excellence of its meat. This species is well known for its delicious flavor, being second to none among the marine fishes of the United States.

BIOLOGY

While it is a very important food fish, it is significant that practically nothing is known regarding the life history of the red snapper. It is not known definitely when or where it spawns. According to Silas Stearns, who has been quoted by Goode, well-developed ovaries are found in those taken from April to July. It seems highly probable that they spawn in deep water, where the young fry remain and grow. This may be inferred as a consequence of the fact that its young are not taken, or are quite rare, in shallow water. The young of other species of *Lutianus*, such as the gray, dog, and lane snappers, the muttonfish, and the schoolmaster are often taken in shallow water by seining. They are more common in shallow water in the southern part of Florida and form more or less a permanent and characteristic feature of the shore fauna from North Carolina southward. The young of the red snapper, however, are either not present in such situations or they are very rare. They should apparently be looked for in deeper water by means of trawling apparatus.

Smith (in Fishes of North Carolina, p. 228, 1907) records young red snappers as having been seined on the beach at Beaufort, N. C. This record, in part at least, is evidently based on an error in identification. I have recently examined in the collection of the Bureau of Fisheries two young specimens, 57 millimeters long, taken at Beaufort, N. C., in 1902, and labelled *L. blackfordii*. These are, apparently, the specimens on which the record in Fishes of North Carolina is based. One of these is a young muttonfish. The other specimen, while strikingly similar in appearance, has 12 dorsal rays, a backward extension of the vomerine teeth, and a few less rows of scales. It is most probably a young lane snapper, although I do not have sufficient material of that size to establish the identification with certainty. Young specimens have been recorded from as far north as Massachusetts, these supposedly being stragglers which have been carried there by the Gulf stream.

NOMENCLATURE AND SYNONYMY

The name *Lutianus blackfordii* was undoubtedly applied to the common red snapper and has been frequently used by American writers for this species. Confusion has resulted from attempts to introduce the name *aya* which was based on Marcgrave's account of some Brazilian fish. Now, if the Brazilian "red snappers" were well known it might have been possible to dispose of this name with some degree of assurance that such action would not have to be changed. Since, however, very little is known regarding these fishes on the coast of Brazil, it is not advisable to associate that name at present with the common American fish.

Jordan in his Manual of Vertebrates (ed. 13, p. 175) and again Jordan, Evermann, and Clark in the new edition of the Check List of Fishes (Report, United States Commissioner of Fisheries, 1928 (1929), p. 2, p. 326, 1930) designate the common commercial red snapper of the Gulf of Mexico *Lutianus campechanus*, purporting to base their action on an investigation by Hildebrand and Ginsburg (Bulletin, U. S. Bureau of Fisheries, Vol. XLII, pp. 77–85, 1927). This is, however, an erroneous interpretation of our conclusions. In the paper cited the name *blackfordii* was applied to the common commercial red snapper of the Gulf. Besides this common species, we have pointed out that there is another species which was apparently confused with *blackfordii*. This second species we have called *campechanus* because it agreed essentially with Poey's description of the type specimen of that species. The relative abundance and geographical range of *campechanus* is unknown at present. A correct interpretation of our paper has been given by Breder (Field Book of Marine Fishes of the Atlantic Coast, pp. 171–172, 1929).

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Lutjanus blackfordi, Jordan and Gilbert, Bull. U. S. Nat. Mus. **16:** 549, 1882.
Lutjanus blackfordi, Jordan and Gilbert, Pr. U. S. Nat. Mus. **5:** 275 (1883) 1882.
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Lutjanus blackfordii, Goode and Bean, t. c., p. 43.
Lutjanus campechianus, Jordan, t. c., p. 125. (Key West.)
Lutjanus vivanus, Jordan and Swain, t. c., p. 453. (Key West.)
Lutjanus blackfordii, Goode, Fish. Ind. U. S. Sec. 1, vol. 1, p. 395, pl. 141, 1884.
Red snapper, Stearns, Fish. Ind. U. S., Sec. 5, vol. 1, pp. 585–594, 1887.
Red snapper, Collins, Rep. U. S. Fish Comm., 1885, pp. 217–305, 1887.
Lutjanus blackfordi, Bean, Pr. U. S. Nat. Mus. **10:** 512 (1888) 1887 (Long Island, N. Y.).
Lutjanus blackfordii, Goode, Amer. Fish., p. 73, fig., 1888.
Lutjanus aya, Jordan, Man. Vert. ed. 5, p. 139, 1888.
Lutjanus blackfordii, Bean, Rep. Commissioner of Fisheries, New York, **19:** 263, pl. 16, fig. 20 (1890) 1891. (Long Island, N. Y.; Massachusetts.)
Lutjanus aya, Jordan and Fesler, Rep. U. S. Comm. Fish., 1889–91, p. 447, pl. 30, 1893.
Lutjanus blackfordi, Moore, Bull. U. S. Fish Comm., **12:** 375 (1892) 1894. (New Jersey.)
Lutjanus blackfordii, Henshall, Bull. U. S. Fish Comm., **14:** 217 (1894) 1895.
Red snapper, Warren, Bull. U. S. Fish Comm., **17:** 331–335 (1897) 1898.
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Neomaenis aya, Smith, Bull. U. S. Fish Comm., **17:** 100 (1897) 1898. (Massachusetts.)
Neomaenis aya, Evermann and Marsh, Fish. Porto Rico, p. 174, col. pl. 20, 1900 (Porto Rico).
Neomaenis blackfordi, Bean, Fish. Long Island, p. 440, 1901. (Massachusetts, Long Island, Block Island.)
Neomaenis blackfordi, Smith, Bull. U. S. Fish Comm. **21:** 33 (1901) 1902. (Massachusetts.)
Neomaenis blackfordi, Bean, Cat. Fish., New York, p. 550, 1903.
Neomaenis blackfordi, Bean, Food, Game Fish., New York, p. 415, fig. col. plate, 1903. (In the Report for the Fish and Game Commission, New York, 1901.)
Lutianus blackfordi, Smith, Fishes North Carolina, p. 287, fig. 127, 1907. (North Carolina.)
Lutianus aya, Schroeder, Rep. U. S. Comm. Fish., 1923, app. 12, p. 19, 1924.
Lutianus blackfordii, Hildebrand and Ginsburg, Bull. U. S. Bur. Fish. **42:** 80, fig. 1 (1926) 1925. (Pensacola, Key West.)
Lutianus aya, Nichols and Breder, Zoologia, **9:** 85, fig., 1927.
Lutianus blackfordii, Breder, Bull. Bingham Oceanographic Collection **1:** 45, 1927.
Lutianus campechanus, Jordan, Man. Vert. ed. 13, p. 175, 1929.
Lutianus blackfordii, Breder, Field book mar. fish., Atlantic Coast, p. 171, 1929.

LUTIANUS CAMPECHANUS

This is, apparently, the common red snapper of the Caribbean Sea and is quite easily distinguishable from the red snapper of the Gulf of Mexico. Hildebrand and Ginsburg (1925) have pointed out the distinctness of the two species, having at the time but a single specimen of *campechanus*. The conclusion of these authors is now corroborated by another specimen, kindly sent to the bureau by Mr. Taylor of the Warren Fish Co., Pensacola, Fla. The specimen was received in fresh condition, on ice. It was one of a lot of 6,000 pounds of the same species obtained at latitude 16° N., longitude 83° 58′ W., on coral bottom, in 35 to 45 fathoms. It agrees closely with the other specimen previously described by the foregoing authors as *campechanus*. In view of the comparatively large catch obtained by one crew at a single locality, it seems probable that the common red snapper of the Caribbean Sea represents this species rather than *blackfordii*. The present species is readily separable from *blackfordii* when specimens are directly compared; and after one becomes familiar with the appearance of the two species and the differentiating structural characters, it is an easy matter to identify them. However, it is difficult to formulate well-marked differences by which the present species may be separated from *vivanus*, although the two are evidently distinct. The chief differences which the specimens at hand indicate are a lesser number of oblique rows of scales below the lateral line; a somewhat shorter snout, which may be expressed by the numerical value of the ratio of the eye to the snout and the snout to the maxillary; a somewhat deeper caudal peduncle when fish of approximately the same size are compared; and one or two less gill rakers on the lower limb of the first gill arch, in *campechanus*. Previous authors who examined fresh material emphasize the yellow color of the iris in *vivanus*. This was also strikingly shown in the smaller specimen of *vivanus* at hand (56 centimeters), but in the larger specimen (63 centimeters) the iris was suffused with pink color, which would seem to show that in older examples this character loses its usefulness to a certain extent.

NOMENCLATURE AND SYNONYMY

The references given below, in part at least, seem to belong to this species which evidently was quite generally confused with *blackfordii* and perhaps with other species of *Lutianus*. It is evident that Poey's original description of *campechanus* was based on a specimen of this species. This author also evidently supposed that the common red snapper of the Gulf of Mexico was the same as his species. His later references to the "pargo guachinango," for which he uses the Latin name *campechanus*, may be taken, therefore, to include also *blackfordii*. Jordan, basing his action on the same supposition, placed *campechanus* in the synonymy of (*aya*) *blackfordii*. However, in view of the data presented here, it seems highly probable that the "pargo guachinango" of the Cuban fishermen is a mixture of the two species. Poey also had two specimens of snappers, one from Santo Domingo and another from the southern coast of Cuba, which he called *aya* and later changed the name to *purpureus*. He stated that they differed from (*profundus*) *vivanus* chiefly in having a red eye. They were evidently examples of the present species, and these references are therefore included here.

?Acara aya, Marcgrave, Hist. Brasil, p. 167, 1648. (Brasil.)

Anthias aya, Bloch, Ichthyol. pl. 227, 1797. (Linnean name for Marcgrave's account.)

Anthias ruber, Bloch and Schneider, Syst. Ichthy. p. 330, 1801. (Based on Marcgrave's account.)

Mesoprion aya, Cuvier and Valenciennes, Hist. Nat. Poiss. **2**: 457 (quarto ed., p. 346), 1828. (Santo Domingo.)

Mesoprion aya, Gunther, Cat. Fish. Brit. Mus. **1**: 198, 1859. (Jamaica; South America.)

Mesoprion campechanus, Poey, Memorias Hist. Nat. Cuba **2**: 149, 1860.

Mesoprion aya, Poey, Reportorio Fis. Nat. Cub. **1**: 267, 1866. (Santo Domingo.)

Mesoprion campechanus, Poey, Repertoria, Fis. Nat. Cuba **2**: 294 (Synopsis), 1868.

Mesoprion campechianus, Poey, Ann. Lyc. Nat. Hist. New York **9**: 317, 1870.

Lutjanus purpureus, Poey, An. Soc. Esp. Hist. Nat. **4**: 102, 1875 (Enumeratio, p. 29). (Santo Domingo; Cuba.)

Lutjanus campechianus, Poey, An. Soc. Esp. Hist. Nat. **4**: 105 (Enumeratio, p. 29), 1875.

Lutjanus campechianus, Jordan and Gilbert, Bull. U. S. Nat. Mus., **16**: 921, 1882.

Lutjanus vivanus, Jordan and Swain, Pr. U. S. Nat. Mus., **7**: 455 (1885), 1884. (Description of type.)

Neomaenis aya, Miranda Ribeiro, Arch. Mus. Nac. Rio de Janeiro, vol. **17**, Lutianidae, p. 8, 1915 (Brazil). (In the description the anal rays are like *blackfordii*. The proportional measurements resemble more *vivanus* or *campechanus*, but these may be due to the size of the specimen described, which is not stated.)

Lutjanus aya, Metzlaar, Rap. Kolonie Curacao, p. 64, 1919. (Aruba.)

Lutianus campechanus, Hildebrand and Ginsburg, Bull. United States Bur. Fish., **42**: 82, fig. 2 (1926) 1927. (Off Honduras.)

Lutianus campechanus, Breder, Bull. Bingham Oceanographic Collection **1**: 46, 1927.

Lutianus campechanus, Beebe and Tee-Van, Zoologica, **10**: 150, fig., 1928 (outline drawing more nearly like *blackfordii*).

Lutianus campechanus, Breder, Field book mar. fish. Atlantic Coast, p. 172, 1929.

Lutianus aya, Nichols, Fish. Porto Rico and Virgin Islands, p. 263, fig. 132, 1929 (drawing more like *blackfordii*). (Ponce, Porto Rico, market.)

LUTIANUS BUCCANELLA

Common names.—Blackfin snapper (Bermuda; Jamaica). Sesi (Cuba). Sesi de lo alto (Cuba). Oreille noire (Martinique). Bouchanelle (Martinique). Calala di hundu (Curacao).

Formulæ.—D. X 14: A. III 8. Scales 67. Gill rakers 12 and 5 rudiments.

Description.—Form oblong, deep bodied, and high backed. The anterior profile rapidly ascending almost to origin of dorsal. Back arched rather high. Lower profile of head gently descending. Belly from gill opening to origin of anal fin a nearly straight line.

Depth at origin of ventrals 2.53; head 2.59 in length to caudal base. Snout medium 2.52; and maxillary but slightly longer than snout, 2.49 in head. Eye rather large, 5.35 in head, 2.12 in snout, and 2.15 in maxillary. Depth of caudal peduncle 3.38 in head.

Extremity of maxillary reaches under anterior margin of eye; articulation of mandible under anterior margin of pupil. Margin of preopercle with a broad, rather well-developed emargination, the middle of the emargination having a rounded spur projecting backward, the outline of the emargination thus being biconcave; interopercle with a well-marked knob; edge of preopercle finely but distinctly serrate, the serræ below the emargination being somewhat coarser.

Outer row of canines in upper jaw, with 2 teeth on either side of symphysis rather larger than others. Mandible with 2 lateral teeth somewhat larger than others. The inner band of villiform teeth in upper jaw extends nearly to angle of mouth, in lower jaw reduced to a short elongate patch on either side of symphysis. Teeth on vomer in a somewhat anchor-shaped patch, the prolongation on the midline rather short. Teeth on tongue in an elongate patch in middle with a small patch in front.

Lower limb of first arch with 12 gill rakers and 5 tubercles on right side, 10 gill rakers with 7 tubercles on left; upper limb with 2 graduated gill rakers at the angle and 6 short stumpy, subequal ones above.

Scales below lateral line rather higher on anterior part of body, than those over anal fin. Scales in lateral line 51, not overlapping one another. Oblique rows of scales quite irregular, 67 rows above lateral line and 56 below; 8 scales in a row from lateral line to origin of dorsal and 13½ to origin of anal; 6 longitudinal rows on cheek.

Origin of dorsal nearly over that of ventral, distance of dorsal origin from tip of snout 2.27, and its base 2.07 in length to caudal base; fourth spine the longest, 2.68; and eighth soft ray the longest, 3 in head, the soft part rounded. Pectoral 1.2 in head, its tip reaching nearly to a vertical through origin of anal. Length of ventral 1.82 in head, its origin under lower angle of base of pectoral, its tip falling short of arms by a distance equal to one-half diameter of eye. Origin of anal under base of first dorsal soft ray, its posterior angle under eleventh dorsal soft ray, length of its base 2.8 in head; posterior outline rounded; third soft ray longest, 2.7; second spine 3.95; third spine subequal to second, 3.90 in head.

Color in fresh condition (*iced specimen*).—Ground color of body light red, more intense above shading to lighter below, centers of scales a much lighter pink. Tail with a broad marginal band of yellow washed with reddish, interrupted in middle by continuation of the predominating red color of rest of tail. On one side the broad marginal interrupted band of yellow, preceded by a definite band of red of a more intense color than base of tail, which is red lightly washed and blended with yellow. Anal and ventral red irregularly margined and washed with yellow. Dorsal red washed and margined with yellow and irregularly shaded with bluish. Pectoral red mingled with yellow above, light pink below. Base of pectoral black, a wide, somewhat diffuse black blotch behind and a narrower curved jet black band in front. A dark diffuse band on the scales covering base of soft dorsal, gradually fading out under spinous dorsal, the band consisting of purplish blue and black pigment mixed with the red ground color. No black lateral spot. Pupil dark blue; iris pinkish yellow on one side and reddish orange on the other. According to Poey, the young, up to about 6 or 7 inches, have the caudal peduncle yellow above. In the large specimen at hand this part was of the same color as the rest of the body.

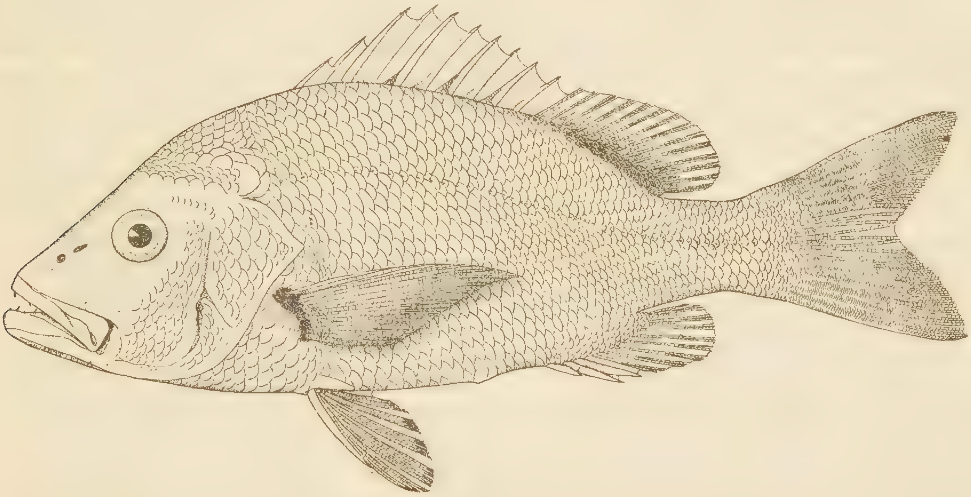

FIGURE 2.—*Lutianus buccanella*. From a specimen 52 centimeters (20.5 inches) total length, brought in by the snapper fishermen in a sea going schooner and taken in the Gulf of Mexico, exact locality not being known. Drawn by Miss Lonella E. Cable.

After being in alcohol nearly all of the bright red and yellow pigments have disappeared. The black at the base of the pectoral and the diffuse dark band at the base of the posterior part of the dorsal persist.

ECONOMIC IMPORTANCE

It is used for food when captured, and its flesh is well liked. It is, however, usually not as common as *blackfordii* and *vivanus*, although it is reported to be common in the market at times. Cuvier and Valenciennes report a weight as high as 20 pounds, but the average is much less, and the species does not seem to attain to the size of the red snapper.

GEOGRAPHICAL DISTRIBUTION AND HABITAT

This is another species of snapper of a predominating red color which occurs in deep water like *blackfordii*. It is taken on rocky bottom, but its range is apparently in deeper water. It has been previously reported from various islands bordering the Caribbean Sea; namely Cuba, Jamaica, St. Thomas, St. Martin, Martinique, and Curacao. It also occurs at Bermuda. The present specimen was obtained by the Pensacola fishermen in the Gulf of Mexico, exact location not being given.

RELATIONSHIP

This species is closely related in its structural characters to the other three deep-water snappers analyzed above. The rounded form of the anal fin distinguishes the present snapper. When the anal fin is broken it may be recognized by its relatively deeper oblong body. A good color mark which persists in preserved specimens is the jet black spot at the base of the pectoral. It is well to mention, however, that in the other three species there may be some black pigment of varying intensity at the base of the pectoral.

NOMENCLATURE AND SYNONYMY

Because of the characteristic jet black spot at the base of the pectoral this species seems to have been generally correctly identified. Goode's (1876) *aya* from Bermuda, judging by the description of the characteristic color marks is apparently of the same species as our specimen. According to Bean (1906), (*aya*) *blackfordii* does not occur at Bermuda. Jordan and Swain (1884), basing their description on a specimen from Cuba, state "body rather slender." This statement does not apply to the present fish and is unlike descriptions of other authors who mention depth of body. It may possibly be due to the size of their specimen, which was 8 inches, but in Poey's figure of a young individual the body is not particularly slender for a snapper. As stated above (p. 270) Cope's *L. torridus* may represent a specimen of this species.

Mesoprion buccanella, Cuvier and Valenciennes, Nat. Hist. Poisson **2**: 455 (Quarto ed., p. 344) 1828. (Martinique; St. Thomas.)

Mesoprion buccanella, Guichenot, Hist. Fis. Nat. Cuba, ed. by Ramon de la Sagro, **4**: 156 (Spanish ed.), 1853. (Cuba.)

Mesoprion caudonotatus, Poey, Memorias Hist. Nat. Cuba **1**: 440 pl. 3, fig. 3, 1854. (Cuba.)

Mesoprion buccanella, Gunther, Cat. Fish. Brit. Mus. **1**: 198, 1859. (Cuba; Jamaica.)

Mesoprion buccanella, Poey, Repertoria, Fis. Nat. Cuba **1**: 267, 1866.

Mesoprion caudonotatus, Poey, l. c. **2**: 158, 1867.

Mesoprion buccanella, Poey, t. c. p. 295 (Synopsis), 1868.

Lutjanus buccanella, Poey, An. Soc. Esp. Hist. Nat. **4**: 101 (Enumeratio, p. 27), 1875.

Lutjanus aya, Goode, Bulletin U. S. Nat. Mus. **5**: 55, 1876. (Bermuda.)

Lutjanus buccanella, Goode, Amer. Jr. Sc. Arts (Ser. 3) **14**: 293, 1877. (Bermuda.)

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Lutjanus buccanella, Jordan and Fesler, Report United States Comm. Fish. 1889–91, p. 445, 1893. (St. Lucia.)

Lutjanus buccanella, Diaz. Peces de Cuba, p. 55, 1893.

Neomoenis buccanella, Jordan and Rutter, Pr. Ac. Nat. Sc. Philadelphia, 1897, p. 108. (Jamaica.)

Lutianus buccanella, Bean, Publ. Field Mus. Nat. Hist. Chicago (Zool. ser.) **7**: 57, 1906.

Neomaenis bucanella [Sic.], Nichols, Amer. Mus. Nat. Hist. **31**: 188, 1912. (Habana market.)

Lutjanus buccanella, Metzlaar, Rap. Kolonie Curacao, p. 63, fig. 23, 1919. (Curacao; St. Martin, West Indies.)

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A BIOLOGICAL STUDY OF THE OFFSHORE WATERS OF CHESAPEAKE BAY[1]

By R. P. COWLES, Ph. D., *Johns Hopkins University*

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INTRODUCTION

One object of this biological survey of Chesapeake Bay has been to make collections and identifications of various animals and plants found there in order to learn more of their distribution and abundance. An equally important object has been to record at the same time some of the environmental conditions which might determine such distribution and abundance. In addition to this it has been the intention of the survey to continue the work for several years in an effort to ascertain what the usual environmental conditions in the bay are, so that when great mortality of fishes, oysters, crabs, clams, etc., occurs there will be data at hand from which to decide as to what unusual changes may have been the cause of the trouble. Finally, it has been hoped that the information obtained concerning salinity, temperature, and plankton content of the water may help at some time in the future to throw light on the laws which govern the migration of fishes, crabs, and other organisms in Chesapeake Bay.

The survey has been a rather general one, many regions having been visited at intervals, so that no one region has been studied intensively—daily for example—although each region has been visited several times during a year. At certain ones, observations and collections have been made every 1½ hours for a period of 24 hours. The temperature and salinity data obtained during several years of observation have been studied. An attempt has been made to work out the distribution of the plankton diatoms and other forms and also to see how they are related to salinity and temperature; but the rôle played by each of these factors can not be conclusively shown, owing to the difficulty of controlling the numerous factors involved. In order to have a better idea of the general physical characteristics of Chesapeake Bay before taking up the discussion of salinity, temperature, and diatom distribution, the following section on the physical features has been included.

PHYSICAL FEATURES

Chesapeake Bay is a large estuary on the eastern coast of the United States lying between latitude 76° to 76° 30′ and longitude 37° to 39° 30′. It forms a deep indentation into the States of Maryland and Virginia, extending inland about 160 nautical miles, varying from 5 to 20 nautical miles in width, and covering an area of approximately 2,800 square miles.[2]

Sounds, small bays, and many small inlets make the outline very irregular. Several moderate-sized rivers empty their waters into the bay. On the west shore, beginning at the head of the estuary, are the Susquehanna, Patapsco, Severn, Patuxent, Potomac, Rappahannock, York, and James Rivers; on the eastern shore the Elk, Sassafras, Chester, Choptank, Nanticoke, and Pocomoke Rivers are the most important ones. The Susquehanna and Potomac, which are the largest, and the rest of the rivers of the western shore supply by far the greater bulk of the fresh water emptied into the bay.

While Chesapeake Bay extends almost directly north and south, its mouth faces the east. Cape Charles and Cape Henry, which guard the entrance to the north and south, respectively, are about 10 nautical miles apart, a distance which is considerably less than the average width of the southern part of the bay. This narrowed condition, together with the occurrence of a tidal delta cut by channels running parallel with the current, have an effect on the velocity of the current through the mouth.

Chesapeake Bay is rather shallow, and there is not a great deal of difference between the upper and lower parts of the bay. Thirty or forty feet is about the average for deep water. Here and there, especially along the eastern shore, there are very deep holes: 150 feet off Kent Island, 114 feet off Poplar Island, 118 feet off Tilghman Island, 114 feet off Taylors Island, 156 feet off Barren Island, 134 feet off Hooper Island, 122 feet off Point No Point, 139 feet off Smiths Point, and 150 feet off Cape Charles City. All of these are close to the eastern shore except the one off Smiths Point, which is near to the western shore, and those off Taylors Island and Point No Point which are in the middle of the bay.

The deep holes along the eastern shore are connected with one another by regions of greater depth than the average of the bay, so that there is a natural deep channel hugging the eastern shore more or less closely and extending from the head of the bay to Point No Point, from which region it crosses over toward the western shore, becoming lost near Rappahannock Spit (Windmill Point). The deep water then continues nearer the eastern shore almost to Cape Charles. (See fig. 1 and Coast and Geodetic Survey charts, Nos. 77 and 78.)

These deep holes are of special interest on account of their permanence, their comparatively rich and unusual invertebrate fauna, and their relation to fishing grounds. It is at the bottom of the deep-water channel that the most saline and densest water is found. Similar deep pools are known in England—for example, the Sloyne in the Mersey River, Lune Deeps in the Irish Sea, and Lynn Well in the Wash. Wheeler (1893) has pointed out that these deeps are permanent because equilibrium of erosion has been attained, and filling up is prevented by the action of the tides combined with the production of eddies. Most of the deep holes of the Chesapeake are located close to the same shore as the submerged "deeps" of the Susquehanna River, studied by Mathews (1917).

Geologists have generally agreed that Chesapeake Bay, in part at least, is a submerged river (McGee, 1888, Lindenkohl, 1891) and that the deep-water channel under consideration is the old bed of the Susquehanna River before the subsidence of the coastal plain. Probably, then, the deep channel was established in geological

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[2] This area has been computed for this survey by the U. S. Coast and Geodetic Survey, and it includes, in addition to Chesapeake Bay proper, Mobjack Bay, Pocomoke Sound, Tangier Sound, Kedges, Holland, and Hopper Straits, Fishing Bay, Honga River, Eastern Bay, Herring Bay, and the entrance to the Choptank River.

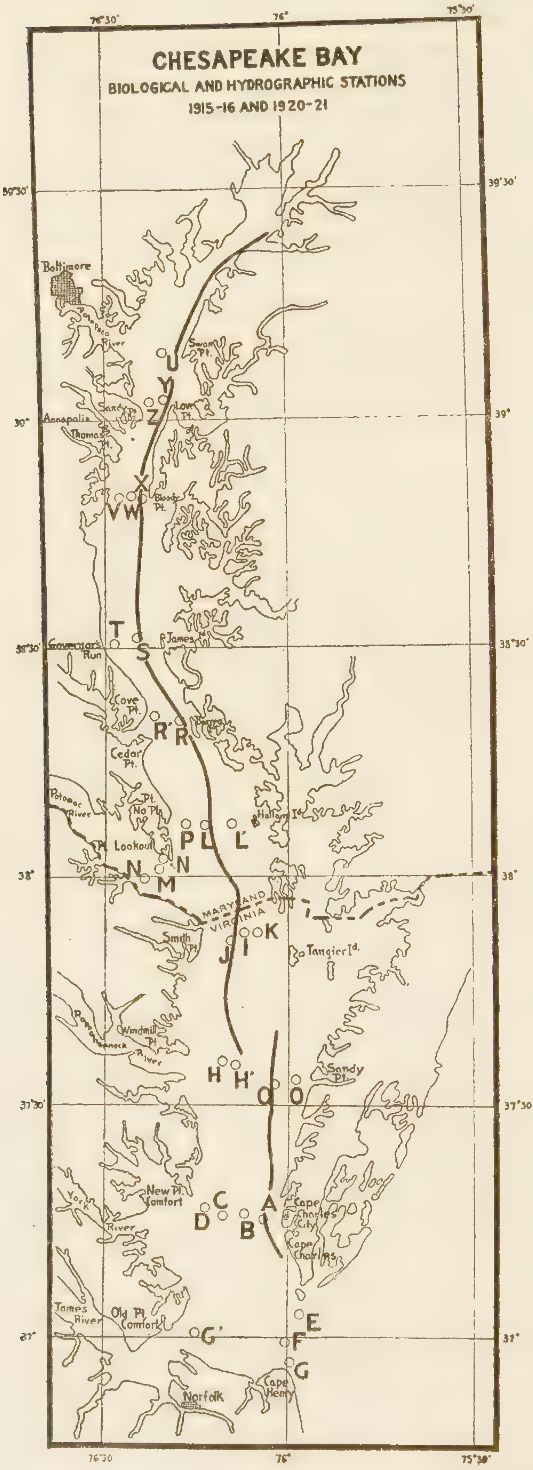
CHESAPEAKE BAY
BIOLOGICAL AND HYDROGRAPHIC STATIONS
1915-16 AND 1920-21
76°30'
76°
75°30'
39°30'
39°
38°30'
38°
37°30'
37°
Baltimore
Patapsco River
Swan Pt.
U
Y
Love Pt.
Sandy Pt.
Z
Annapolis
Thomas Pt.
X
Bloody Pt.
V W
T
Governor's Run
S
James Id.
Cove Pt.
R' R
Sharps Id.
Cedar Pt.
Potomac River
Pt. No Pt.
Holland Id.
P L L'
Pt. Lookout
N N
M
MARYLAND
VIRGINIA
K
Smith Pt.
J I
Tangier Id.
Rappahannock River
Windmill Pt.
H H'
Sandy Pt.
Q O
New Pt. Comfort
C
D
A
B
Cape Charles City
Cape Charles
York River
James River
Old Pt. Comfort
G'
E
F
G
Norfolk
Cape Henry

FIGURE 1

times when the coastal plain was more elevated than at the present time. While there does not seem to be any good reason for believing that the ebb and flood of the tide during recent times has cut the deep channel, yet it is known that erosion to a marked degree is taking place along the eastern shore of the bay (Hunter, 1914).

Like most estuaries, Chesapeake Bay has, in general, a muddy bottom, resulting in part from the deposition of large amounts of organic matter brought down from the land by the rivers; in part from the settling of the dead bodies of marine, brackish-water, and fresh-water organisms, and in part from the settling of finely divided mineral matter. The latter is commonly called clay. This mixture of clay and organic matter, which assumes a soft, sticky condition when wet, undoubtedly contains some iron sulphide resulting from the action of the sulphates in the sea water on the iron compounds brought from the land. The mixture is characteristic of estuaries, ocean waters near the land, and deeps outside of the 100-fathom line, according to Murray and Irvine (1893). They have given it the name "blue mud" or clay. This "blue mud" varies somewhat in color from a black to a blue-black and to a brown in the Chesapeake, depending, probably, on the amount of organic matter and sulphide of iron present, as pointed out by Murray and Irvine.

The consistency of the blue mud is not the same in all regions. In some places it forms a rather firm, cakelike layer without a soft surface, in others the typical plastic, claylike mud with a soft surface, and in still other localities a soft, puddled mud. Samples of the bottom of Chesapeake Bay show, as a rule, that the blue-mud layer is not very thick except in certain regions, such as the mouths of rivers. Usually a sample cut out of the bottom to a depth of 2 or 3 inches shows a lower layer of sand, clay, or shells, and often the blue mud is more or less mixed with these materials. While the bottom of Chesapeake Bay is largely muddy, the shores are usually sandy, and this latter condition is especially characteristic of the southern half of the bay.

The movements of the water of Chesapeake Bay are complicated. The ebb and flood of the tide, the outflow of many rivers which aid the ebb and hinder the flood, the greater volume of river water entering from the western shore, eddies produced by headlands at the mouths of rivers and inequalities on the bottom, currents moving in more or less opposite directions at surface and bottom in the same locality, variations in rainfall, seasonal changes in temperature, and strong winds are factors which govern the movements of the water in the bay. There are no very strong currents, a condition which has been noted by the Coast and Geodetic Survey (1916), Grave (1912), and the author.

METHODS

Some preliminary investigations of much value were made by Lewis Radcliffe, of the Bureau of Fisheries, in 1915, 1916, and 1917, but this work was discontinued in March, 1917. In January, 1920, the writer continued the investigation under the United States Bureau of Fisheries and was in charge until March, 1922.

During 1916 and 1920, 13 general cruises over the bay were taken on the U. S. S. *Fish Hawk*. In addition to these, 2 preliminary cruises were made in 1915, another on the U. S. S. *Roosevelt* outside of the bay near the entrance in 1916, 4 special cruises in the bay to study hydroids in 1916, 2 special cruises in 1921, and 2 in 1922. The 24 cruises, including dates, station numbers, and other data, are given below:

Cruise
I. October 22–27, 1915, stations 8336 to 8365.
II. December 1–10, 1915, stations 8366 to 8402; 24-hour station 8394.
III. January 15–22, 1916, stations 8403 to 8441.

Cruise
IV. January 27–February 1, 1916. (Outside of Capes Henry and Charles) (on U. S. S. *Roosevelt.*) Stations 8442 to 8457.
V. March 6–12, 1916, stations 8458 to 8496.
VI. April 21–26, 1916, stations 8497 to 8535.
VII. May 22–30, 1916 (for hydroids), stations 8536 to 8549.
VIII. June 2–12, 1916, stations 8550 to 8588.
IX. July 17–31, 1916, stations 8589 to 8627; 24-hour station 8617.
X. August 30–September 2, 1916 (for hydroids), stations 8628 to 8650.
XI. September 8–12, 1916, stations 8651 to 8686.
XII. December 16–17, 1916 (for hydroids), stations 8687 to 8696.
XIIa. March 20–22, 1917, (for hydroids), stations 8697 to 8706.
XIII. January 10–16, 1920, stations 8707 to 8737.
XIV. March 6–12, 1920, stations 8738 to 8769; 24-hour stations 8738 and 8760.
XV. May 1–8, 1920, stations 8771 to 8799.
XVI. July 3–9, 1920, stations 8800 to 8831; 24-hour stations 8800 and 8811.
XVII. August 21–26, 1920, stations 8832 to 8866; 24-hour stations 8855 and 8866 (8832 to 8836 outside of bay).
XVIII. October 15–21, 1920, stations 8867 to 8896; 24-hour stations 8867 and 8877.
XIX. December 4–10, 1920, stations 8897 to 8928; 24-hour stations 8918 and 8928.
XX. January 22–27, 1921, stations 8929 to 8959; 24-hour stations 8948 and 8959.
XXI. March 28–April 2, 1921, stations 8960 to 8988; 24-hour stations 8960 and 8970.
XXII. May 30–June 3, 1921, stations 8989 to 9019; 24-hour stations 9008 and 9019.
XXIII. January 21–25, 1922, stations 9020 to 9047; 24-hour station 9039.
XXIV. March 25–30, 1922, stations 9048 to 9078; 24-hour stations 9067 and 9078.

The general cruises were made at approximately equal intervals, and on each cruise about 30 "areas" or regions were visited; and, for the most part, the same areas were visited on each cruise. These areas, which were circular in outline, were charted as 183 meters (200 yards) in diameter, and their positions were selected in such a way as to make lines across the bay covering all localities of interest from Cape Charles and Cape Henry to Swan Point and North Point. Each area was designated by a capital letter, as may be seen in Figure 1. While they were recorded as measuring 183 meters in diameter, the actual stations made were not spread out much within the area during the time the writer was in charge; that is, the various stations within the area were made according to bearings which were kept the same, usually, from cruise to cruise, so that the positions of the various stations in an area did not vary a great deal.

Water samples for quantitative plankton study and for ascertaining the salinity and temperature of the water were collected, using the Green-Bigelow water bottle and the Negretti-Zambra reversing therometer. About half of each sample of water (approximatley 500 cubic centimeters) was run into a special type of storage bottle with a patent stopper and rubber washer. The collection of these samples was then made a matter of record in the log, and later the samples were shipped to the United States Geological Survey, where, under the supervision of Dr. R. C. Wells, their salinity was determined by titration for chlorine. From the salinity data the densities were calculated.

The other half of the contents of the water bottle was used as a plankton sample. Such samples were later sent to Dr. Bert Cunningham, of Duke University, Durham, N. C., who determined the species, counted the number of organisms per cubic centimeter for each species, and studied the distribution of the species in the bay. These samples gave a fairly good idea of the abundance of most plankton organisms with the exception of copepods and some other of the more active species. While the observations and collections described above were being made the ship was allowed to drift unless the wind or currents were so strong as to carry it out of the 200-yard area. When the latter occurred, the ship was given enough headway to keep within the area.

In order to supplement the information obtained from the plankton samples mentioned above, surface towings were taken with townets made of silk bolting cloth (No. 6 and No. 18 or 20) and a bottom towing with a similar No. 18 townet. The mouth of each surface net measured 30.5 cntimeters (1 foot) in diameter and that of the bottom net one-half meter in diameter. During the towing, which lasted 10 minutes, the speed of the vessel was, as a rule, 2 knots. Samples obtained in this way were shipped to specialists for identification and in some cases for study from the point of view of distribution. The Copepoda, Medusæ, and Sagittæ were studied by Prof. C. B. Wilson, Dr. Henry B. Bigelow, and the author, respectively. Mr. Glassman and the author have undertaken a study of the distribution of the Mysidæ. Most of the Crustaceæ were sent to the United States National Museum, where they have been identified.

A large beam trawl, whose runners were fitted with flat wooden shoes to prevent sinking in the mud, was used for the collection of fishes, sponges, ascidians, hydroids, bryozoans, and echinoderms. The duration of each trawling was 5 minutes; and the speed of the vessel was, as a rule, 3 knots. The fishes have been studied by Messrs. Hildebrand and Schroeder, the echinoderms by Dr. Hubert L. Clark, the ascidians by Dr. William G. Van Name, the bryozoans by Prof. Raymond C. Osburn, the hydroids by Prof. C. W. Hargitt, and the sponges by Prof. H. V. Wilson.

Such animals as mollusks, annelids, holothurians, leeches, and many lower organisms which are found on the bottom or burrowing in the mud or sand, were captured either by the mud bag attached to the beam trawl or by the "orange-peel bucket." The latter is a small commercial dredge that bites to a depth of about 0.5 meter, bringing up about 0.1 cubic meter of the bottom. The mollusks were sent for study to the National Museum, the annelids to Dr. A. L. Treadwell, the holothurians to Dr. Hubert Lyman Clark, and the leeches to Dr. J. P. Moore.

SALINITY

The determination of the salinity of a body of water is one of the necessary procedures in a biological survey because the degree of salinity is believed to be a factor in determining the distribution of some of the animals and plants found in the water and because it is desirable to know how much the salinity varies from time to time. For this reason water samples were collected at each station visited, and their salinity determined by titration for chlorine, from which the salinity was calculated.

The data on surface and bottom salinity and temperature will be discussed first, since many of the organisms collected and counted were taken at those levels. In this same part of the paper the vertical distribution of salinity and temperature will be taken up. After that, under the heading of seasonal distribution, data from intermediate waters will be compared at equivalent depths such as 20 and 30 meters.

SURFACE SALINITY AT MOUTH AND HEAD

The salinity of Chesapeake Bay, like that of other long bays and estuaries, gradually decreases, with very few exceptions, from the mouth to the head; and the bay is known as a brackish body of water, although the failure, as a rule, of the fresh waters from the land and the saline waters of the sea to mix completely, and the variation in the volume of fresh and salt water entering the bay, result in different degrees of brackishness (Cowles, 1920). The surface data at the mouth of the bay show a vari-

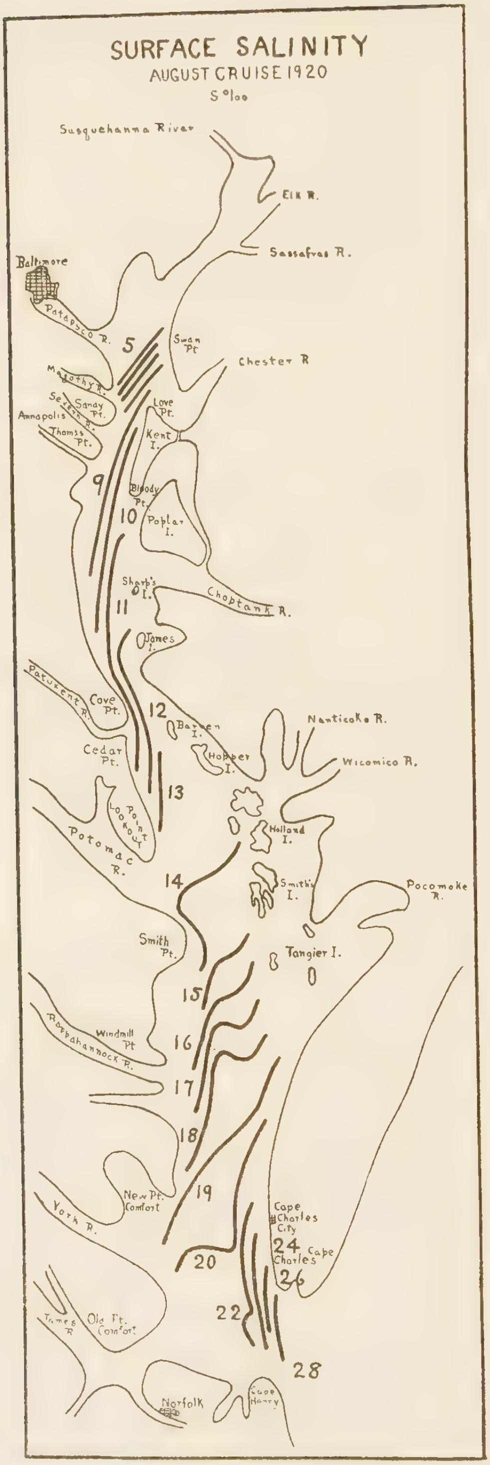
SURFACE SALINITY
AUGUST CRUISE 1920
S ‰
Susquehanna River
Elk R.
Sassafras R.
Baltimore
Patapsco R.
5
Swan Pt.
Chester R
Magothy R.
Sandy Pt.
Severn R.
Annapolis
Love Pt.
Thomas Pt.
Kent I.
9
Bloody Pt.
10
Poplar I.
Sharp's I.
Choptank R.
11
James I.
Patuxent R.
Cove Pt.
12
Barren I.
Nanticoke R.
Hooper I.
Wicomico R.
Cedar Pt.
13
Point Lookout
Holland I.
Potomac R.
14
Smith's I.
Pocomoke R.
Smith Pt.
Tangier I.
15
Windmill Pt
16
Rappahannock R.
17
18
New Pt. Comfort
19
York R.
Cape Charles City
24
Cape Charles
20
26
22
James R.
Old Pt. Comfort
28
Norfolk
Cape Henry

FIGURE 2

ation in salinity from about 19.00 to 30.00 grams per liter in the region of areas *G*, *F*, and *E*, while near Balitmore at area *U* there is a variation from about 3.00 to 11.00 grams per liter. So far as our records show (January, March, April, June, July, September, 1916; January, March, May, July, August, October, December, 1920; January, March–April, May–June, 1921; and January, March, 1922), the surface salinity never reached 31.00 at the mouth, but occasionally it was reduced to less than 19.00—for example 18.36 at *G* in March, 1922. On the other hand, at area *U* the surface salinity never reached 12.00 and sometimes dropped below 3.00—for example 2.26 in May, 1920. It will be seen then that the range of surface salinity from head to mouth may be large, for example 2.26 at *U* to 25.40 at *F* in May, 1920.

SURFACE SALINITY FROM MOUTH TO HEAD

A good general idea of the variation of the surface salinity from the mouth to the head of Chesapeake Bay may be obtained from Figure 2, which is a map[3] of the bay showing the surface salinity for a cruise in August, 1920. During this cruise the range of surface salinity was from 28.94 (area *E*) at the mouth to 4.75 (area *U*) at the head. The arrangement of the isohalines[4] shows clearly that the most saline surface water was uniformly on the east side of the bay from head to mouth. Similar maps for other months are shown in Figures 3, 4, 5, and 6.

The greatest decrease per unit of distance in surface salinity took place between *E*, *F*, *G*, and *D*, *C*, *B*, *A* (from 28.94 to about 20.00 in a distance of about 15 miles) near the mouth, and this is indicated by the crowding of the isohalines. (August, 1920). A similar condition was noted in the Baltic Sea by Pettersson (1894). Next in order was that between *Y*, *Z*, and *U* near the head. The decrease from the mouth of the Potomac River to *Y*, *Z*, as well as from *D*, *C*, *B*, *A* to the Potomac River was very gradual. A study of the data from the other cruises shows that while there is considerable variability in the rate of decrease from cruise to cruise in the regions mentioned, the condition during August is an average one. The amount of decrease in salinity per unit of distance from *J*, *I*, *K* into the mouth of the Potomac River at *N*, *M*, *N'* is usually rather high, but it will be noted by referring to the map (fig. 2) for August, 1920, that the isohalines do not show such a condition. This is probably due to the unusual time elapsing between the times of making the observations at *J*, *I*, *K*, and *N*, *M*, *N'*.

VARIATION OF SURFACE SALINITY ACROSS BAY

One of the most striking characteristics of part of Chesapeake Bay is the higher surface salinity on the eastern than on the western side of the bay (Cowles, 1925). Such a distribution of salinity is most marked from the region of James Island to the mouth, although during certain cruises—for example June 1916, January, August, and December, 1920—the surface salinities obtained on the eastern side of the bay were highest from the mouth to the region of Baltimore. A study of the profiles indicates that this condition is due to the fact that the deep-water channel which contains the most saline bottom water lies on this side throughout most of its extent and to the fact that a large volume of fresh water from the rivers of the western shore presses the more saline water toward the eastern shore. Now, taking up in order

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[3] No high degree of accuracy can be claimed for such a map, since the water samples could not be collected simultaneously at the stations and since the salinity fluctuates somewhat back and forth at a station with the tide. However, in the opinion of the writer the map presents a good general picture of the distribution of the surface salinity during the period of the cruise.

[4] An isohaline is a line connecting points of the same salinity in a plane.

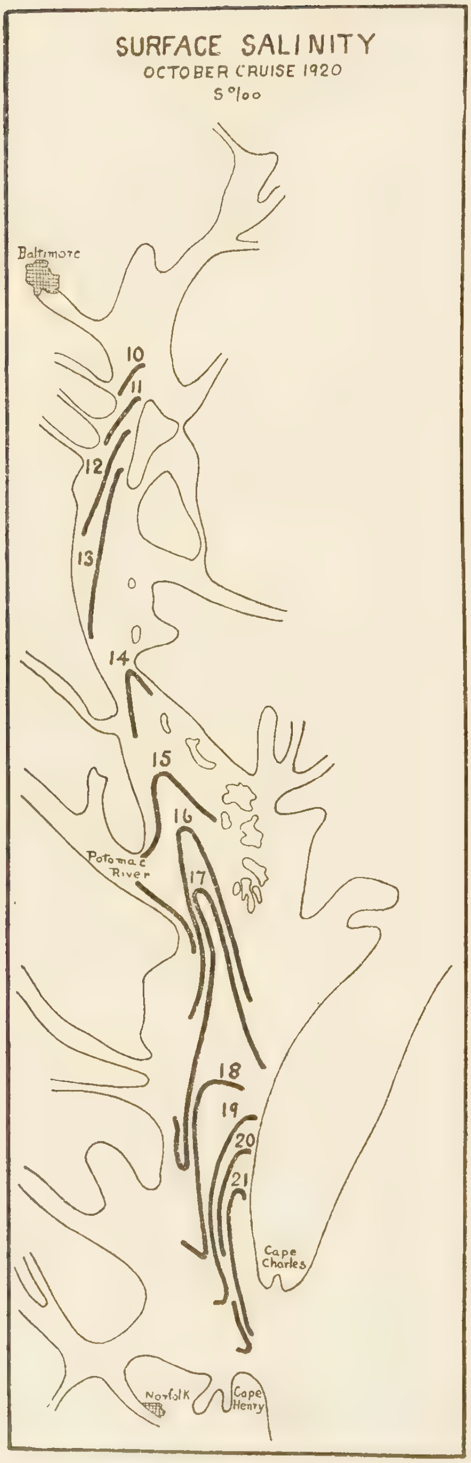
SURFACE SALINITY
OCTOBER CRUISE 1920
S °/oo
Baltimore
10
11
12
13
14
15
16
17
Potomac River
18
19
20
21
Cape Charles
Norfolk
Cape Henry

FIGURE 3

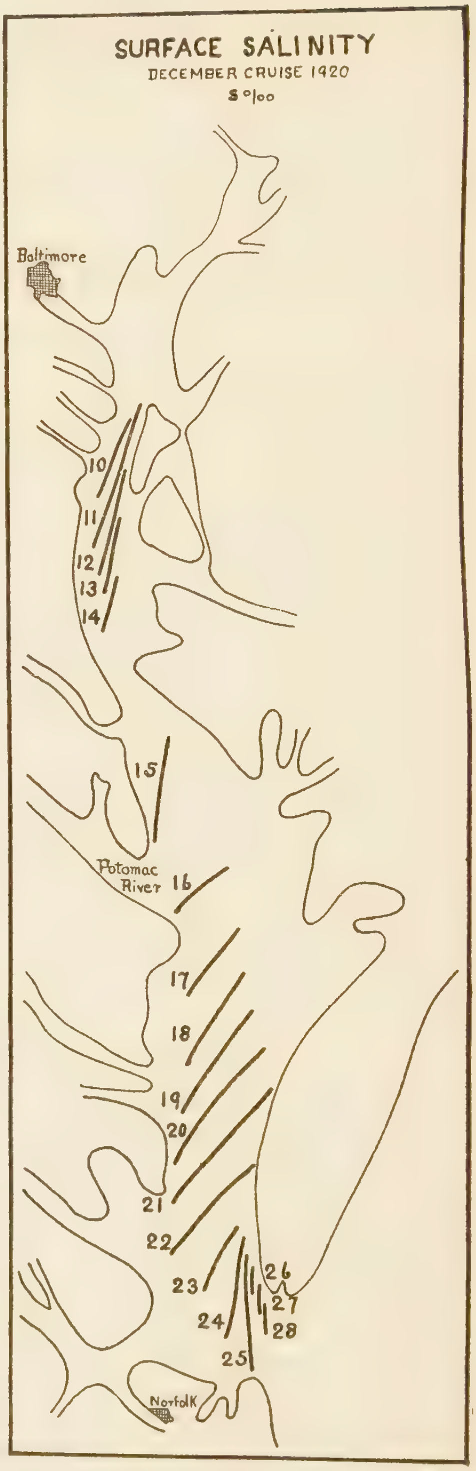
SURFACE SALINITY
DECEMBER CRUISE 1920
S °/oo
Baltimore
10
11
12
13
14
15
Potomac River
16
17
18
19
20
21
22
23
24
25
26
27
28
Norfolk

FIGURE 4

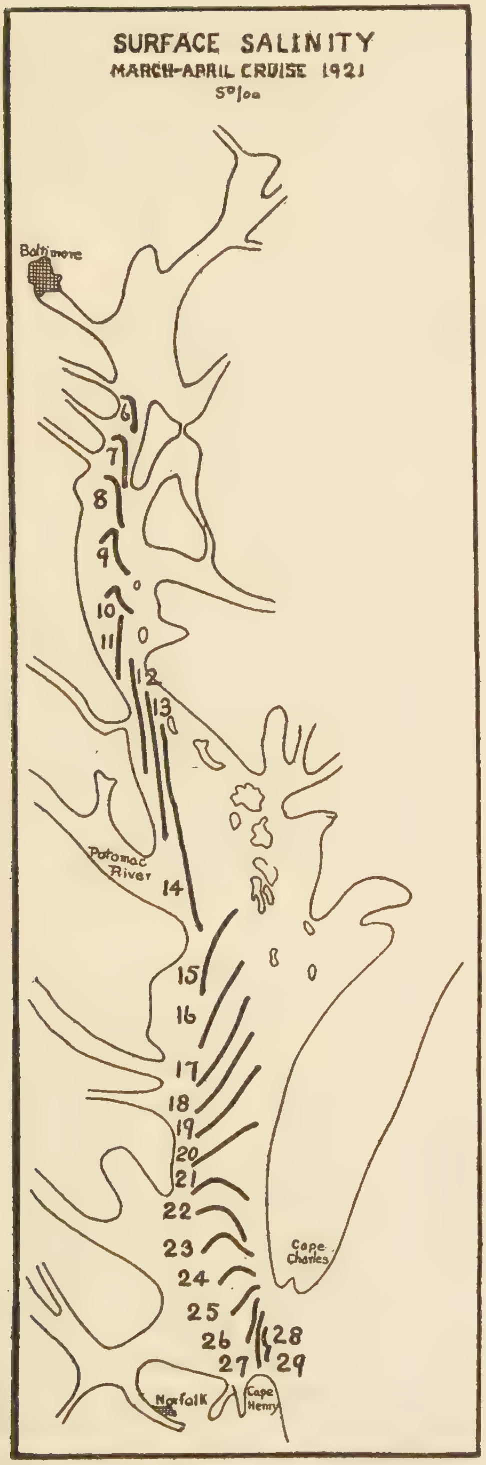
SURFACE SALINITY
MARCH-APRIL CRUISE 1921
S°/oo
Baltimore
6
7
8
9
10
11
12
13
Potomac River
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Cape Charles
Norfolk
Cape Henry

FIGURE 5

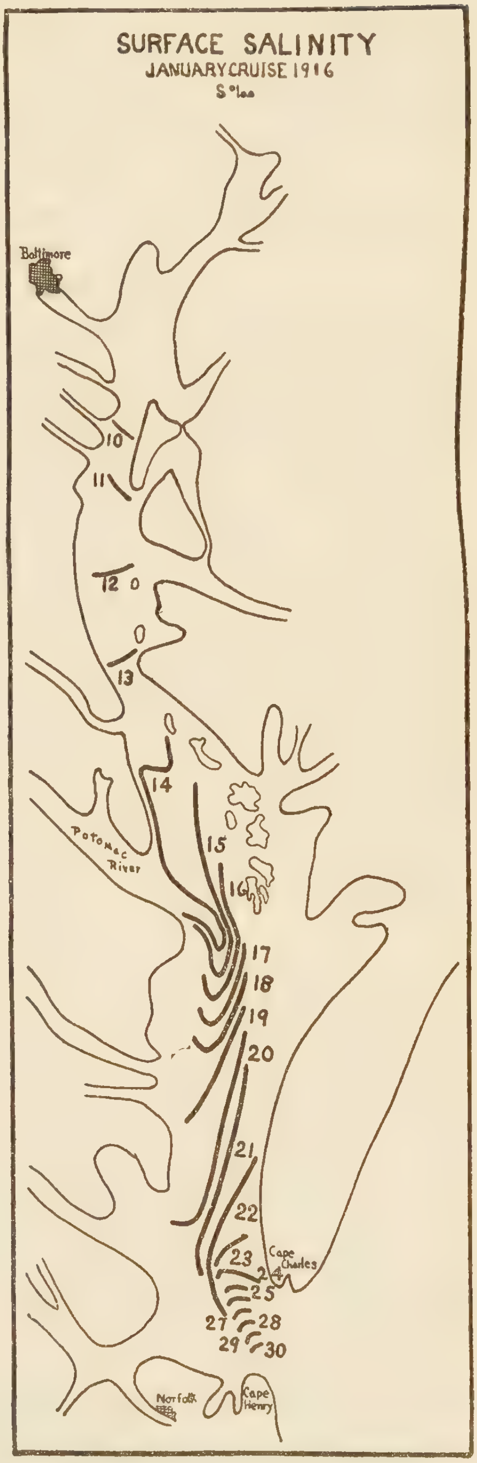
SURFACE SALINITY
JANUARY CRUISE 1916
S°/oo
Baltimore
10
11
12
13
14
Potomac River
15
16
17
18
19
20
21
22
23
24
25
27
28
29
30
Cape Charles
Norfolk
Cape Henry

FIGURE 6

from the mouth to the head the several lines extending across the bay, we find the following:

Salinity data for the line *G, F, E* during 9 of 11 cruises showed that the surface salinity was higher on the east side [5, 6]; line *D, C, B, A*, 13 of 13 on the east side; line *H, H′, Q, O*, 16 of the 16; line *J, I, K*, 12 of the 13; line *N, M, N′*, 10 of the 12; line *P, L, L′*, 10 of the 11; *R′, R*, 11 of the 11; line *T, S*, 9 of the 11; line *V, W, X*, 8 of the 14; and line *Z, Y*, 9 of the 15[6]. It will be noted that toward the head the condition mentioned gradually changes until along the line *Z, Y* the higher surface salinity occurs on the east side with considerably less frequency.

BOTTOM SALINITY AT MOUTH AND HEAD

In this discussion of the bottom salinities it should be understood that samples from the same area collected on different cruises were not taken at exactly the same depth and that when comparisons are made between bottom salinities in different parts of the bay it is done merely to show under what different conditions of salinity organisms at the bottom may be living.

The bottom salinities recorded on our cruises for the mouth of the bay varied from about 26.00 to a little over 32.00 at area *G*, while in the region of Baltimore at area *U* they varied from about 6.00 to 17.00. These data, which are from the same cruises as those mentioned above, with the exception of July and September, 1916, January, 1920, and January, 1922, when no data were obtained, show that the bottom salinity at area *U* on one occasion was as low as 6.54 (May cruise, 1920) and did not reach, at any time observed, a greater salinity than 17.38 (December cruise, 1920). At area *G* in the mouth the bottom salinity reached the lowest point observed, 25.77, during the May, 1920, cruise. While the maximum salinity observed was 32.57 in January, 1916, at area *G*. The range of bottom salinities, then, from head to mouth, may be very great—for example, 6.54 at *U* to 25.77 at *G* in May, 1920.

It is of interest that the salinities at area *U* closely approach a point where the density is so low that, if continued for a long period of time, it is harmful to oysters (Moore, 1897).

BOTTOM SALINITY FROM MOUTH TO HEAD

A study of the data for the August, 1920, cruise shows that during this cruise the range of bottom salinities was from 31.74 (area *G*) at the mouth to 15.21 (area *U*), as compared with 28.94 (area *E*) at the mouth to 4.75 (area *U*) at the head for surface salinity during the same cruise. As in the case of the surface salinities, the greatest decrease per unit of distance, if one leaves out of consideration the high salinities of deep holes, took place between *E, F, G*, and *D, C, B, A*. At the mouth of the Potomac River, *J, I, K* to *N, M, N′*, the decrease was quite marked; but in the long stretches from the mouth of the Potomac River north to *Y, Z*, and south to *D, C, B, A* changes per unit of distance were small, a condition which holds true for the surface salinity. An examination of the data for the rest of the cruises shows in general similar relative amounts of decrease in bottom salinities per unit of distance for the regions just mentioned.

An interesting exception to the gradual decrease in bottom salinity from the mouth to the head of the bay is seen at *T, V*, and *Z*. These areas, which lie on the west side of the bay from Governors Run to the mouth of the Magothy River, have fairly similar depths—for example, 9.15 meters at *T*, 10 meters at *V*, and 12.81 meters

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[5] More accurately on the north side, since this line runs about north and south.

[6] Only cruises for which there were sufficient surface salinity determinations are included in the counts.

at *Z* (August cruise, 1920). On 10 of the 15 cruises for which we have data during 1916, 1920, 1921, and 1922 the bottom salinity increased, passing from *T* to *Z*—that is, toward the head of the bay. While there is not much difference in depth from *T* to *Z*, yet it will be seen that the latter is a little deeper than the former and this is probably enough to account for the condition mentioned. At the surface the salinity decreases almost invariably from *T* to *Z*.

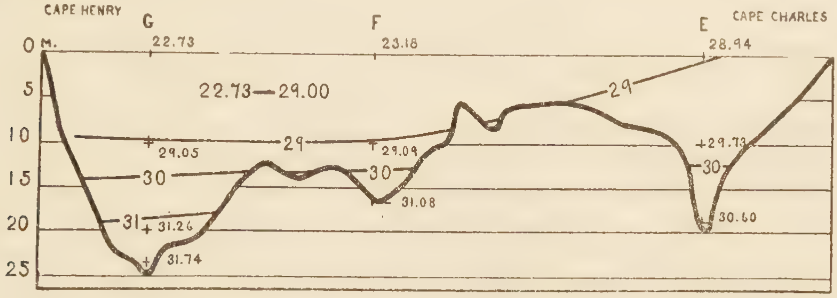

FIGURE 7.—Salinity profile from Cape Henry to Cape Charles, August 22, 1920

VARIATION OF BOTTOM SALINITY ACROSS BAY

It will be remembered that there seems to be a strong tendency for the most saline surface water to lie near the eastern shore of the bay but that this tendency decreases in the upper part until at *Z*, *Y* the saltier water occurs with more nearly an equal frequency on the eastern and western sides. The most saline bottom water, however, as might be expected, owing to its higher density finds its way into the deep-water channel of the bay and may be traced during every cruise along the eastern shore and almost invariably through *Y*, *X*, *S*, and *R*, then to the middle of the bay through *L*, then nearer the western shore through *J*, again on the eastern shore through *Q* and *A*, and finally out through the mouth of the bay at *G*. (See map showing deep-water channel, fig. 1.)

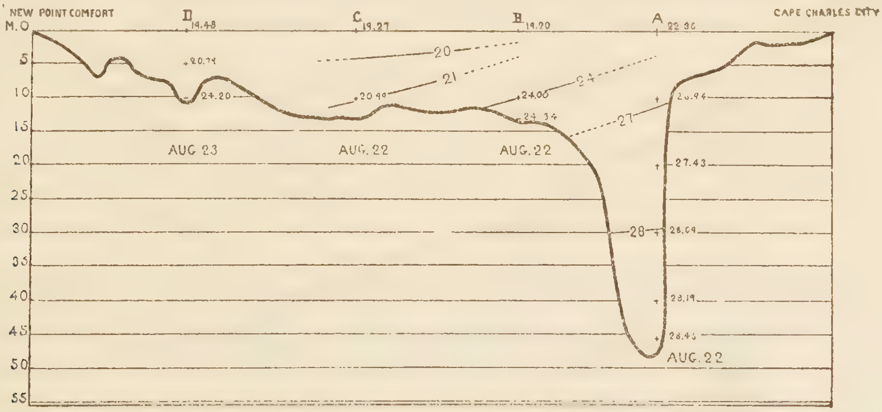

FIGURE 8.—Salinity profile from New Point Comfort to Cape Charles City, August 22, 1920

VERTICAL DISTRIBUTION OF SALINITY

Profiles across the bay show that especially along the deep-water channel, sometimes in the region of the mouths of rivers, and usually at the mouth of the bay, a sharp increase in salinity occurs somewhere between the surface and about the 20-meter level. (Figs. 7, 8, 9.) This phenomenon, which is a well-known one for regions where fresh and salt water meet, is due to the lighter fresh water flowing over the heavier salt water. (See Pettersson, 1894, and Murray and Hjort, 1912.) The sharp increase occurs usually at about 10 meters, but there are exceptions, and at times, depending upon the flow of fresh water from the rivers, the character of the tides, the winds, the temperature, etc., the line of demarcation may be nearer the surface or below 10 meters. While the stratification just described was very marked during most of our cruises, there were times in the spring and winter months when the water approached a condition of equal salinity from surface to bottom. (Fig. 10.) A discussion of this phenomenon will be taken up under seasonal distribution of salinity.

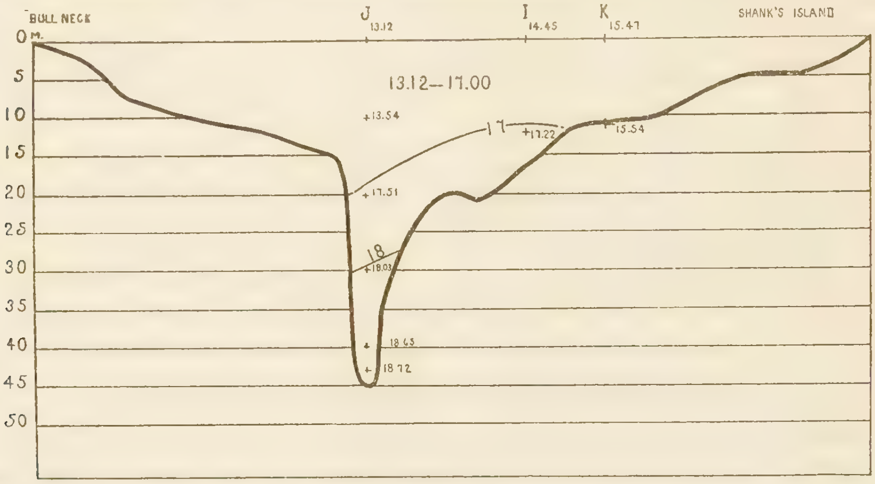

FIGURE 9.—Salinity profile from Bull Neck to Shanks Islands, January 24, 1921

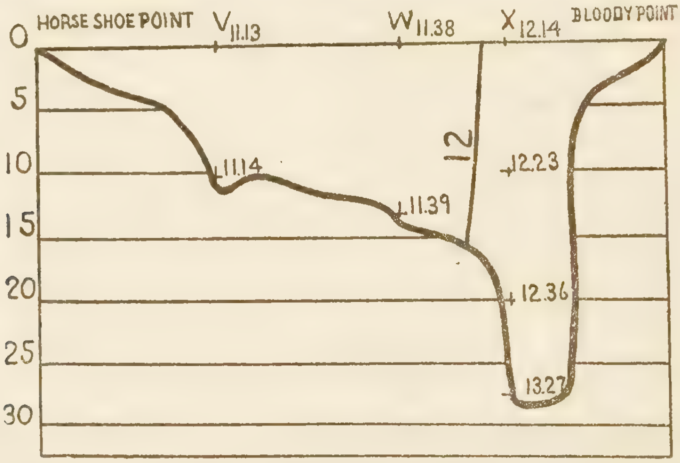

FIGURE 10.—Salinity profile from Horse Shoe Point to Bloody Point, January 27, 1921

In addition, the vertical distribution of salinity as seen in profiles illustrates graphically the conclusions arrived at above from a study of the data for surface and bottom salinities; namely, that the more saline surface water, in general, lies nearer the eastern shore, although in the northern part of the bay it may be found on either side with almost equal frequency, and that the more saline bottom water follows the deep-water channel *Y*, *X*, *S*, *R*, *L*, *J*, *Q*, *A*, and *G*.

An interesting condition, which shows on practically all cruises, is the one along the line *J*, *I*, *K* just below the mouth of the Potomac River. The most saline bottom water is found at area *J*, located on the deep channel near the western shore, while the most saline surface water lies on the eastern side, usually at area *K* or at least at area *I*. The density profiles indicate that the condition mentioned is due to the pressure of the Potomac River water, which, coming from a westerly direction, crowds the more saline surface water overlying the deep channel toward the east. A similar but less marked condition occurs along the line *P*, *L*, *L′*.

SALINITY OF WATER DURING WINTER

It has been pointed out that there is a comparatively large decreasing range of salinities from the mouth of the bay to the head throughout the year. This range varies from time to time, but there is no evidence in our data to show that there is any uniform seasonal fluctuation in the amount of range.

Inspection of the salinity values of the January cruises taken in 1916, 1920, and 1922 shows that they were generally higher than those of the January, 1921, cruise. This condition is probably correlated with the fact that January, 1921, was an exceptionally mild month. (Table 1.) (See section on salinity during the spring.)

TABLE 1.—*Temperatures and salinities at surface, 20 meters, and 30 meters, during January, for various years and areas*

Areas	January, 1916		January, 1921						January, 1922					
	Temperature, °C., surface	Salinity, surface	Temperature, °C.			Salinity			Temperature, °C.			Salinity		
			Surface	20 meters	30 meters	Surface	20 meters	30 meteas	Surface	20 meters	30 meters	Surface	20 meters	30 meters
G	4.1	23.40	5.9	6.0	--------	19.22	28.10	--------	12.9	5.9	--------	23.91	29.15	--------
A	3.3	22.74	4.9	4.9	4.8	--------	--------	--------	4.4	4.5	4.1	23.96	25.71	25.89
J	1.4	15.14	3.9	3.9	4.0	13.12	17.51	18.30	3.4	3.2	2.7	--------	--------	--------
L	1.8	14.36	3.1	3.0	3.7	13.64	13.80	16.80	2.6	2.4	2.8	15.46	20.31	20.46
R	1.1	13.66	2.6	3.4	3.7	--------	--------	--------	1.4	2.7	2.5	15.81	19.54	19.86
S	1.1	12.77	2.7	--------	--------	--------	--------	--------	1.7	--------	--------	13.17	--------	--------
X	1.0	11.13	2.0	2.1	--------	12.14	12.36	--------	.8	3.2	--------	13.26	18.95	--------
Y	1.2	9.22	1.6	[1] 3.8	--------	10.88	[1] 14.46	--------	--------	--------	--------	--------	--------	--------
U	.6	6.83	1.1	--------	--------	6.44	--------	--------	--------	--------	--------	--------	--------	--------

[1] At 20.13 meters.

Throughout the year the salinity usually increases with the depth (Katohalin). This might be expected in a body of water where there is fresh water from rivers flowing over tidal saline water entering from the ocean, even though currents, river floods, low air temperatures, and winds tend at times to alter that condition. A discontinuity in salinity was frequently seen during the winter cruises and, although the water was at times almost homohaline from the surface to the discontinuity layer, it was seldom that even an approach to complete homohalinity along the deep-water channel was observed. The salinities for January, 1916, are typical: Area *U*, surface 6.83, 4 meters 8.44, 9 meters 12.92, 15 meters 14.31; area *L*, surface 14.36, 5 meters 14.92, 10 meters 15.72, 17 meters 16.87, 25 meters 19.27, 31 meters 19.87; area *G*, surface 23.40, 8 meters 27.20, 17 meters 32.54, 22 meters 32.57. Occasionally, however, as on January 25, 1921, at area *L*, an approach toward an homohaline and homothermous condition was observed. The salinities were as follows at 7.35 p. m.: Surface 14.36, 10 meters 14.26, 20 meters 14.34, 30 meters 14.64, 33.9 meters 14.78. The temperatures were: Surface 3°, 10 meters 3°, 20 meters 2.9°, 30 meters 3°, 33.9 meters 3.3°. The wind, temperature, and direction of the current at this time were favorable for profound changes in the relation of waters of different salinities. There was a moderate breeze blowing from north-northeast at about 15 miles per hour, the sea was rolling, and there was an outgoing current moving slowly almost without exception from surface to bottom throughout 24 hours of observation. These conditions, together with a rapid fall in air temperature two days previous to the time when the water samples were collected and a continued low air temperature of about −4° C., were probably the cause of the almost homothermous and homohaline relations.

SALINITY OF WATER DURING SPRING

The salinity data for 1916 show that the deep-water salinity values found in the bay were considerably less, with very few and unimportant exceptions, during the March cruise than during the January cruise. The same was true for 1920 and 1922. This relation did not hold in the lower half of the bay between the January and March-April cruises of 1921. The exceptional mildness of the month of January, resulting in a flood of fresh water, probably accounts for the difference. The evidence on the whole from the four years indicates, nevertheless, that in the spring there is a decrease in the salinity of Chesapeake Bay. Such a condition would be expected, if for no other reason than that in the spring months the maximum discharge occurs in the larger rivers which empty into Chesapeake Bay. (Table 2.)

Table 2.—*Temperatures and salinities at surface, 20 meters, and 30 meters, during March, for various years and areas*

Areas	March, 1916		March-April, 1921						March, 1922					
	Temperature, °C., surface	Salinity, surface	Temperature, °C.			Salinity			Temperature, °C.			Salinity		
			Surface	20 meters	30 meters	Surface	20 meters	30 meters	Surface	20 meters	30 meters	Surface	20 meters	30 meters
G	3.7	28.15	12.1	--------	--------	27.74	--------	--------	8.9	--------	--------	18.36	--------	--------
A	3.1	20.14	12.1	11.3	11.4	21.56	24.62	28.23	7.3	7.0	6.7	19.33	23.91	25.10
J	2.3	15.17	10.9	--------	--------	14.30	--------	--------	8.1	6.2	6.5	11.62	17.89	18.26
L	1.8	15.25	11.4	--------	--------	14.26	--------	--------	7.2	5.7	5.6	12.21	16.95	17.12
R	1.6	14.94	10.2	10.7	--------	13.94	14.20	--------	7.7	4.9	5.2	--------	--------	--------
S	1.7	14.61	10.8	--------	--------	10.87	--------	--------	7.3	--------	--------	11.89	--------	--------
X	1.1	12.92	10.5	9.9	8.4	7.43	10.38	13.53	8.2	4.5	--------	9.84	15.26	--------
Y	1.2	10.55	12.4	--------	--------	5.26	--------	--------	9.2	5.2	--------	5.65	15.79	--------
U	1.4	9.25	12.7	--------	--------	3.61	--------	--------	9.0	--------	--------	5.22	--------	--------

A discontinuity in the vertical distribution of salinity is usual along the deep-water channel for the spring cruises, although the salinity is as a rule lower than at other seasons of the year. At times, however, as in the early part of March, 1920, when one of our cruises was made, the vertical distribution of salinity approached homohalinity at several areas in the northern part of the bay. Only during the winter (fig. 10) and spring cruises has this condition been observed. On the morning of March 6 we began to take samples at area *U* and continued their collection every hour and a half until 11.45 p. m. Throughout the day the salinities were unusually similar from surface to bottom—for example, at 1.15 p. m., surface 10.05, 3 meters 10.11, 6 meters 10.17, and bottom (9 meters) 10.71. At station 8748, between areas *R* and *L*, a similar condition was found: Surface 16.11, 10 meters 16.14, 20 meters 16.14, 30 meters 16.16, 35 meters 16.22. The conditions were favorable for such distribution of salinity. At area *U* the sea was rough, a 15-mile wind blew from the northwest, ice floes were in the bay, there was no dominating flood current, and the air temperatures were exceptionally low. During the night of March 5, 1920, an exceptionally large drop in temperature occurred—from 46° F. (7.8° C.) to 18° F. (−7.8° C.), a drop of 28° F. (15.6° C.), in Baltimore.

SALINITY OF WATER DURING SUMMER

A discontinuity in the vertical distribution of salinity was distinctly seen on the summer cruises. This might be expected, since the time for spring freshets was over and there was less chance of a disturbance in the stability of the layers. The maximum rains in the Chesapeake Bay region usually occur during the summer months. While they may cause a distinct decrease of temperature in the surface layers and while, of course, the surface layers are diluted to some extent, our data, except for the July, 1916, cruise in the upper part of the bay, do not show any appreciable decrease in the salinity at the surface or in the deeper layers during the months of maximum precipitation. (Table 3.) The indications are that the effects of precipitation on the bay itself are not very important in changing the salinity. No tendency toward a homohaline condition was observed during the summer cruises along the deep-water channel, and even in shallow water the range from surface to bottom was usually considerable. Typical summer conditions for *U*, July 3, 1920, were as follows: Surface, 6.80, 5 meters 8.49, 10 meters 12.24, 12.5 meters 13.31, at 11.28 p. m.; and for *L* at 10.19 a. m., July 6, 1920, surface 12.50, 10 meters 14.66, 20 meters 19.72, 30 meters 20.20, 36.6 meters 20.22. That the salinity values of the midsummer and late summer cruises showed an increase over the low salinity values of the spring cruises may be seen from the data given under the section "Salinity at 30 meters and averages of salinities."

SALINITY OF WATER DURING AUTUMN

So far as our records show, the discontinuity in vertical distribution of salinity persists in a striking manner into the autumn. During this season the discharge from rivers is at its minimum and the weather is usually exceptionally mild on Chesapeake Bay. Possibly, but not probably, almost homogeneous vertical distribution of salinity, occurred at times, but our records do not show that such changes have taken place. However, only two cruises have been made during the autumn—one in September, 1916, and the other in October, 1920. During the cruises of the autumn months just mentioned the salinities, like those of the summer, were higher than those of the spring cruises. (Table 4.)

TABLE 3.—*Temperatures and salinities at surface, 20 meters, and 30 meters, during July and August, for various years and areas*

Areas	July, 1916		August, 1920					
	Temperature, ° C., surface	Salinity, surface	Temperature, ° C.			Salinity		
			Surface	20 meters	30 meters	Surface	20 meters	30 meters
G	23.5	24.90	27.0	17.2	--------	22.73	31.26	--------
A	24.3	22.54	27.0	22.2	21.3	22.36	27.43	28.09
J	--------	--------	26.0	26.0	25.2	--------	--------	--------
L	--------	--------	25.5	25.5	25.0	13.72	13.77	19.76
R	25.2	10.21	24.2	--------	--------	12.83	--------	--------
S	26.0	8.46	--------	--------	--------	--------	--------	--------
X	25.2	5.41	23.7	--------	--------	10.65	--------	--------
Y	26.0	4.02	23.5	--------	--------	9.46	--------	--------
U	--------	--------	23.5	--------	--------	4.75	--------	--------

TABLE 4.—*Temperatures and salinities at surface, 20 meters, and 30 meters, during September, October, and December, for various years and areas*

Areas	September, 1916		October, 1920						December, 1920					
	Temperature °C., surface	Salinity, surface	Temperature, ° C.			Salinity			Temperature, ° C.			Salinity		
			Surface	20 meters	30 meters	Surface	20 meters	30 meters	Surface	20 meters	30 meters	Surface	20 meters	30 meters
G	--------	--------	20.4	--------	--------	20.28	--------	--------	10.5	11.3	--------	25.20	30.22	--------
A	23.4	23.59	20.4	20.0	19.4	21.99	26.18	27.02	10.3	10.2	10.2	--------	--------	--------
J	24.1	14.54	20.0	19.3	19.5	14.87	22.80	--------	9.5	9.7	10.0	--------	--------	--------
L	--------	--------	19.7	19.5	19.3	15.89	20.20	22.24	8.7	10.1	10.1	15.14	19.51	20.10
R	--------	--------	--------	--------	--------	--------	--------	--------	8.6	9.5	9.9	14.93	18.35	19.68
S	23.9	12.05	20.2	--------	--------	13.72	--------	--------	7.8	--------	--------	14.69	--------	--------
X	23.9	11.09	19.4	--------	--------	13.70	16.00	--------	7.9	8.8	--------	12.42	12.84	--------
Y	24.4	9.56	19.2	--------	--------	--------	--------	--------	7.4	--------	--------	10.64	--------	--------
U	--------	--------	19.8	--------	--------	9.25	--------	--------	7.0	--------	--------	9.13	--------	--------

SEASONAL SURFACE SALINITIES DURING 1916

I have stated that the salinity values obtained during the different seasons indicate that in the spring the salintiy in Chesapeake Bay decreases markedly, that in the summer it begins to increase again, reaching its highest degree ordinarily in the fall and winter. Inspection of the surface salinity values obtained at areas *G, F, D, C, B, A, H, J, I, M, X,* and *Z* for the cruises of January, March, April, June, July, and September, 1916, tends to support this contention so far as surface water is concerned (Table 5), although in these data, as well as those which have been given above, the water samples were not taken simultaneously at the various areas, so that they were not collected necessarily at the same stage of the tide. However, the rather close uniformity in the seasonal fluctuation of the salinity values for each area indicates strongly that they show, in a comparative way, the salinity conditions in the bay.

TABLE 5.—*Surface salinities during 1916*

Areas	January	March	April	June	July	September	Areas	January	March	April	June	July	September
G	23.40	28.15	21.92	22.92	24.90	--------	H	18.53	17.30	13.21	14.33	15.99	16.31
F	30.48	25.23	18.89	25.14	26.69	27.54	J	15.14	15.17	10.80	12.97	16.31	14.54
D	19.85	18.46	17.18	17.30	21.46	--------	I	13.37	15.79	11.55	13.24	11.78	15.21
C	19.98	18.91	15.84	17.81	21.62	21.55	M	13.73	13.59	11.09	11.76	9.99	13.26
B	21.47	18.93	16.28	21.17	21.62	21.65	X	11.13	12.92	5.88	8.30	5.41	11.09
A	22.74	20.14	18.46	22.11	22.54	23.59	Z	9.29	10.01	3.35	3.10	4.25	10.16

SEASONAL SURFACE AND 30-METER SALINITIES FOR AREA L DURING 24 HOURS

As further evidence supporting the belief that the salinity decreases in the spring and rises again to a maximum in the latter part of the year we have the data from water samples collected usually at 1½-hour intervals through 24 hours. Such data bring out the tidal fluctuation in salinity during that period as well as the changes from cruise to cruise (1920).

The 24-hour observations were not begun at area *L* until the July cruise, but the single surface salinity determinations for area *L* in March and May were 15.87 and 7.30, respectively. The data for the July and October cruises (1920) show an increase over those of the May cruise, while on the cruise during the unseasonably mild month of January, 1921, the salinity values decreased again. (Table 6.)

A similar condition may be seen for the salinity values at the 30-meter depth. The single determination at 30 meters during the March cruise was 16.50, while those of the July and October cruises (1920) were higher and those of the January, 1921, cruise lower.

TABLE 6.—*Surface and 30-meter salinities at area L, taken at frequent intervals during 24 hours, July and October, 1920, and January, 1921*

Period	Surface	30 meters	Period	Surface	30 meters	Period	Surface	30 meters	Period	Surface	30 meters
July 6-7, 1920			*July 6-7, 1920*—Continued			*Oct. 18-19, 1920*—Continued			*Jan. 25-26, 1921*		
10.19 a. m.	12.50	20.20							10.30 a. m.	13.64	16.80
11.49 a. m.	12.56	20.04	4.19 a. m.	12.76	19.18	9.00 p. m.	15.92	21.93	Noon	13.64	15.34
1.19 p. m.	12.57	19.98	5.49 a. m.	12.40	20.01	10.30 p. m.	15.85	21.92	1.30 p. m.	13.97	16.12
2.49 p. m.	12.53	20.10				Midnight	15.38	22.04	3.00 p. m.	14.15	14.87
4.19 p. m.	12.60	20.00	*Oct. 18-19, 1920*			1.30 a. m.	15.79	21.88	4.30 p. m.	14.52	14.87
5.49 p. m.	12.68	20.10	10.30 a. m.	15.90	22.30	3.00 a. m.	15.77	21.82	7.35 p. m.	14.26	14.64
7.19 p. m.	12.68	20.04	Noon	15.89	22.24	4.30 a. m.	15.68	21.75	3.00 a. m.	14.59	14.59
8.49 p. m.	12.66	20.00	1.30 p. m.	15.90	22.34	6.00 a. m.	15.76	21.61	4.30 a. m.	14.38	14.87
10.19 p. m.	12.58	19.68	3.00 p. m.	15.86	22.32	7.30 a. m.	15.71	21.99	9.00 a. m.	14.20	14.34
11.49 p. m.	12.68	19.69	4.30 p. m.	15.95	22.22	9.00 a. m.	15.81	21.87			
1.19 a. m.	12.68	20.06	6.00 p. m.	15.98	21.35						
2.49 a. m.	12.73	20.02	7.30 p. m.	15.92	21.85						

RELATION OF SEASONAL SALINITY TO SALINITY OF COASTAL WATER

The investigations of H. B. Bigelow (1917b) along the eastern coast of the United States in the region of Chesapeake Bay indicate that "the salinity of the coast water, so far as is known, rises during autumn and winter * * *". Water samples collected outside of the mouth of Chesapeake Bay on January 20, 1914, and January 27, 1916, at the depth of 18 meters showed that the salinity was 33.57 and 33.35, respectively. (See Bigelow, 1917b, pp. 54, 55, 60; and 1922, pp. 124, 181, 184.) While no water sample was collected below the surface at this same station in November, 1916, other data indicate that the salinity at 18 meters was about 33.00; at the surface in this same locality the salinity was 32.52. On the other hand, the salinity at 18 meters on August 21, 1916, was 31.02. These data, which were the ones directly concerned with Chesapeake Bay in Bigelow's study, indicate a higher degree of salinity for the coastal water in the winter than in the summer.

The salinity determinations inside of Chesapeake Bay are, on the whole, in accord with Bigelow's tentative statement concerning the rising of the salinity of the coastal water during autumn and winter.

SALINITY AT 30 METERS AND AVERAGES OF SALINITIES

The data that we have for salinities at 30-meter depths, although limited, support the view that the coastal water increases in salinity during the latter part of the year after the floods of the first part of the year. At area *A*, off Cape Charles City, the salinities at 30 meters on the following 1920 cruises were: March, 20.81; August, 28.09; and October, 27.02. Near the middle of the bay at area *L* during the same year and at the same depth they were as follows: March, 16.15; July, 20.26; August, 19.76; October, 22.24; and December, 20.10. Farther up the bay at area *R* the data at 30 meters for two cruises during 1920, were: March, 16.06; and December, 19.68. No samples were collected at 30 meters during the January cruise.

Those areas visited during 1920 also show higher surface salinities during the cruises of the latter part of the year. The following are examples: Area *G*, January, 28.19; March, 20.64; May, 19.26; July, 20.54; August, 22.73; October, 20.28; and December, 25.20. Area *A*, January, 23.32; March, 18.70; July, 21.72; August, 22.36; October, 21.99; and December, 22.78. Area *H*, January, 16.85; March, 16.22; May, 11.95; July, 15.57; August, 16.45; October, 16.74; and December, 18.25. Area *X*, January, 13.57; March, 13.77; May, 5.81; July, 9.40; August, 10.65; October, 13.70; and December, 12.42.

During the year 1922 only 2 cruises were made, 1 in January and 1 in March; and a distinctly lower salinity was found during the latter cruise. At area *A*, near the mouth of the bay, the salinities at 30 meters for January and March were 25.89 and 25.10, and for area *L*, near the mouth of the Potomac River, 20.41 and 17.12. A similar condition was found at the surface and at 20 meters.

Averages of the surface salinities of 12 widely distributed areas (*G*, *F*, *D*, *C*, *B*, *A*, *H*, *J*, *I*, *M*, *X*, *Z*) during the cruises of 1916 show the seasonal condition mentioned above: January, 18.26; March, 17.88; April, 13.70; June, 15.85; and July, 16.88. Surface salinities for the September cruise were markedly higher than those of the summer and spring cruises, but, owing to the fact that the data for areas *G* and *D* are lacking, no average is given for that cruise. Also the data at each area for each cruise show a similar relation: Area *A*, January, 22.74; March, 20.14; April, 18.46; June, 22.11; July, 22.54; and September, 23.59. Area *H*, January, 18.53; March, 17.30; April, 13.21; June, 14.33; July, 15.99; and September, 16.31. And area *X*, January 11.13; March, 12.92; April, 5.88; June, 8.30; July, 5.41; and September, 11.09.

The data show that there was a minimum degree of salinity in Chesapeake Bay during those cruises taken in the spring months of 1916 and 1920, and that, in general, higher salinities occurred during the summer, fall, and winter cruises. Also in 1922 the data show that salinities of the March cruise were distinctly lower than those of the January cruise, but in the winter and spring of 1921 this relation was disturbed in the lower part of the bay. It has been pointed out that the winter months, December, 1920, and January and February, 1921, were unusually mild in Maryland and that probably that accounts for the low salinities during that time.

A study, then, of the salinities of the various cruises taken on Chesapeake Bay favors the view that a decided decrease in salinity occurs during the early part of the year and that later in the year there is a tendency for it to increase again. Such a view is in keeping with the time of occurrence of the maximum discharge of the water from the large rivers entering the bay, and, as we shall see in the next section, with the tendency for the more saline deep water of partly marine origin to make its way up into the bay during the latter part of the year.

RELATION OF DIRECTION AND VELOCITY OF CURRENT AT 24-HOUR STATIONS TO SEASONAL SALINITY

It is evident that the degree of salinity depends on (1) the amount of fresh water brought in by rivers or by local precipitation, (2) on the amount of saline water brought in by the sea combined with (3) the mixing of these waters, and (4) the amount of evaporation of the water. The records of the water-supply department of the United States Geological Survey show that the maximum discharges of such large rivers as the Potomac and Susquehanna at points somewhat above their entrance into the Chesapeake occur during the spring months, March, April, or May, and that the minimum discharges are in August, September, or October. These conditions alone would tend to establish a low salinity in the bay during the spring and a higher one during the summer, fall, and winter.

On the other hand, Chesapeake Bay is a tidal estuary, although the tidal currents are weak compared to those of many other estuaries. A clearly defined ebb and flood of the water were made out at the areas mentioned below during the spring and summer cruises, but the current velocities, according to current-meter records, were quite low. During the fall and winter cruises, however, when the current velocities were a little higher, the alternating incoming and outgoing currents characteristic of tides were usually not so evident, judging from our data obtained during 24-hour observations at area *U*, near Baltimore, and at areas *R*, *L*, and *Q*, lower down in the bay. These results are of interest in connection with the observations made by Canadian observers. (See Dawson, 1897.) Changes due to local precipitation and evaporation can not be made out, as a rule, from our data. Other changes due to more dominant causes mask them.

The fact that the water at 30 meters as far north as a little below Baltimore (area *R*) may have a salinity of 20.00 shows, of course, that water of partly marine origin makes its way up in the bay. It is difficult to ascertain what factors bring this condition about and whether the higher salinities sometime after the spring freshets are due to decreased pressure from the fresh water, to reaction currents resulting from outflow of surface fresh water, to the pressure of oceanic water resulting from the northerly drift of the highly saline water of equatorial regions, to a combination of these factors, or to other factors. Irregularities in tidal flow due to hydrological conditions in the upper part of the bay, the occurrence of spring and neap tides, and probably many other factors which add complexity make it difficult to analyze the movements of the waters of Chesapeake Bay.

Current records, however, at 24-hour stations do show at times what appears to be a persistent, although not continuous, tendency for the rather highly saline waters of the lower layers to move slowly into the bay. Areas *L* and *R* are both deep-water areas situated in the deep channel where the movements of the more saline water may be observed. The records indicated that with the approach of autumn and during the winter months there was at times a persistent tendency for the highly saline water of the lower layers to push its way slowly inwards, thus masking the tidal movements, and that during the spring and summer cruises this tendency was not so evident, with the result that the tidal currents were more clearly seen. A similar condition has been observed in Christiana Fiord by Hjort and Gran (1900). The movement inward during the autumn and winter cruises did not seem to be dependent on the conformation of the bottom, nor could it be related clearly to the occurrence of spring and neap tides. Undoubtedly, however, a nontidal factor (see Marmer, 1925, and Zeskind and LeLacheur, 1926) was responsible for this ingoing current. The wind, as an example, blows more frequently from a northerly direction during the winter, while during the summer the more common direction is southerly, according to Spencer. This would tend to move the fresher surface water oceanward in the winter and as a result produce the so-called "reaction stream" of Ekman (1876); the "reaction current" of Helland-Hansen and Nansen (1909); "compensatory bottom current," Johnstone (1923); "induction current," Cornish (1898); "undercurrent," Dawson (1896), in which the deeper more saline water moves inward from the sea. In summer, on the other hand, with the wind from the opposite direction such a tendency would not exist.

The discharge from rivers (another nontidal factor) would also bring about conditions such as those just described, but it is not clear why the undercurrent moving in an ingoing direction is so marked during the winter months, when the discharge from the rivers is not ordinarily at is height.

Finally, it may be mentioned that so far as the time of the occurrence (autumn and winter) of a strong tendency toward an incoming current in the lower layers is concerned, it would be permissible to relate that phenomenon to the influence of the North Equatorial Stream and the Atlantic gyral (Gulf Stream eddy) of which it is a part. It is known (Johnstone, 1923) that the axis of this stream or drift and also the rest of the Atlantic gyral shifts in a northerly direction during the summer, reaching its northermost position in the autumn; and that in such regions as the North Sea, Irish Sea, and Baltic Sea the culminating effect of this moving water occurs in March or in some regions later. Chesapeake Bay might be expected to show the effect of this movement of saline water during the autumn and winter, but while the data on salinity, temperature, current velocity, and current direction show that there is at times an unusual inflow of saline water into the bay during the autumn and winter, there is no conclusive evidence to support the theory that this condition is brought about by the northerly shift of the Atlantic Stream gyral alone or even in part.

TEMPERATURE OF WATER

It is well known that certain organisms are adapted to one range of temperatures and that others flourish under a different range. Also, it is known that there are some which are very hardy, being able to live between widely separated extremes, and that others are sensitive and can exist only within a small range of temperatures. Such a dependence on temperature must necessarily be an important factor in determining the latitudinal, seasonal, and vertical distribution of aquatic animals and plants. Furthermore, the degree of temperature undoubtedly is often an important factor in regulating the rate of reproduction, and extreme temperatures may at times cause great mortality. Finally, it is believed that temperature is a factor which has an influence on the migration of some fishes. For these reasons water temperature data have been recorded. A discussion of the data follows.

SURFACE TEMPERATURE AT MOUTH AND HEAD

The temperature data for the surface water collected at the mouth of Chesapeake Bay on the various cruises showed a variation from about 4° C. to 27° C. at area *G*, while at the head (area *U*) near Baltimore temperatures ranging from about 0.0° C. to 25° C. were found. The data for January, March, April, June, July, September, 1916; August, October, December, 1920; January, March–April, May–June, 1921; and January, March, 1922, show a maximum surface temperature of 27° C. at area *G* in August, 1920, and only on one cruise a temperature as low as 3.7° C. (at area *G* in March, 1916).

At area *U*, near Baltimore, the highest surface-water temperature recorded on our cruises was in August, 1920, 24.8° C., and the lowest, 0.3° C. in January, 1921. The maximum surface temperature seems to have been about the same for the mouth and the head; but the minimum was lower at the head than at the mouth, due undoubtedly to the presence of ice floes and to slightly lower air temperatures during the winter.

Temperature data were collected also during January, March, May, and July, 1920. The thermometers used during this period were tested for accuracy and the necessary corrections were determined; but since they were not of the reversing type, and hence not suitable for work at depths, it is considered best to disregard the results. However, the surface readings for the latter part of the first week in March, 1920, were frequently below 0.0° C.; and it is the writer's belief that the temperature of the surface water in the upper part of the bay reached temperatures below 0.0° C.—for example $-0.2°$ C. (salinity 13.67) on March 7, 1920, at area *W*.

SURFACE TEMPERATURE FROM MOUTH TO HEAD

Leaving out of consideration, for the moment, the surface temperature conditions along the line *E*, *F*, *G*, which extends across the mouth of the bay, an examination of the surface temperatures observed during the cruises of the coldest months of the year suggest that, in general, there is a decrease from a region near the mouth (line *D*, *C*, *B*, *A*) to the head. The data consistently show a graded decrease; and such a condition would be expected, but it must be remembered that our observations were not made simultaneously at the thirty-some areas distributed over the bay and that, in fact, it took several days to complete the collection of the data. It is hardly necessary to state that there was some change in the temperature conditions from day to day so that a map showing isotherms for a cruise can give only a general idea of the conditions over the whole bay. Such a map for the January, 1921, cruise is shown in Figure 13. The decreasing range of surface temperatures for January, 1916, 1921, and 1922 may be seen well in Table 1 where series are given for areas from the mouth to head.

During the cruises of the spring, summer, and fall the surface temperature values with one exception did not show the decreasing range from the mouth to the head. Although not taken simultaneously, they indicate a more variable condition and smaller range during those seasons. The exception mentioned above was found during the August, 1920, cruise, when, as may be seen from Table 3 and Figure 11, the data showed a decreasing range of surface temperatures from the mouth to the head. These figures were rather surprising until it was seen by reference to the weather map of the United States Weather Bureau that shortly before the observations were made at areas *D*, *C*, *B*, and *A* (August 21) the air temperature at Norfolk reached 90° F. (32.2° C.) and at Baltimore only 70° F. (21.1° C.).

Much variability in temperature distribution is to be expected, especially at the surface, in a shallow body of water where a difference of 20° F. in the temperature of the air over two different areas may occur at the same time so that maps showing isotherms can give only approximate pictures of conditions. The map for the cruise of August, 1920 (fig. 11), shows a range of surface temperatures from 23° near the head to 27° near the mouth, an unusual condition for which an explanation has just been offered. The 27° isotherm is of special interest in this connection. A more usual condition for the warmer months is shown on the map for June, 1916. (Fig. 15.)

The greatest differences in surface temperatures per unit of distance from mouth to head were found, as in the case of salinity, near the mouth of the bay. They occurred during the cruises of the warmer months, when the heated waters of the rivers and bay meet the colder waters of the ocean. As examples, in August, 1920, there was a difference of almost 5° C. between *E* and *A*; in June, 1916, there was almost 4° C. difference between the two areas. During the cruises of the colder months, however, such a rapid change in passing from the line *G*, *F*, *E* to the line *D*, *C*, *B*, *A* was not observed. (Figs. 11, 12, 13, 14, and 15.)

The range of surface temperatures passing from *D*, *C*, *B*, *A* out through the mouth of the bay by way of areas *G*, *F*, *E* showed almost invariably a decrease in temperature during the cruises of the warmest months, and an increase in temperature during those of the coldest months.

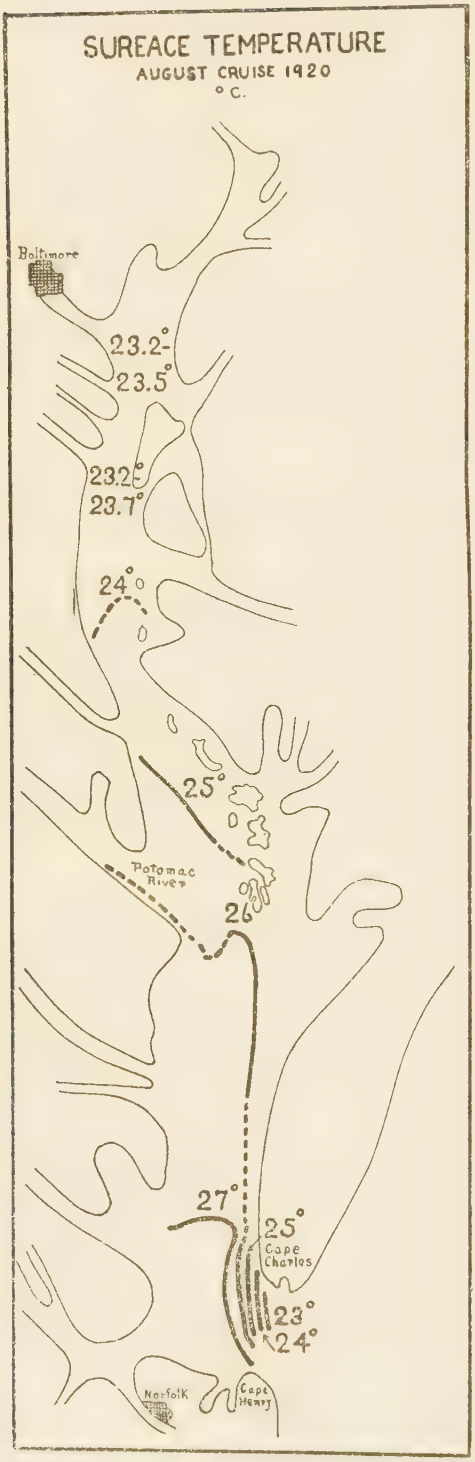
SURFACE TEMPERATURE
AUGUST CRUISE 1920
°C.
Baltimore
23.2°-
23.5°
23.2°-
23.7°
24°
25°
Potomac River
26°
27°
25°
Cape Charles
23°
24°
Norfolk
Cape Henry

FIGURE 11

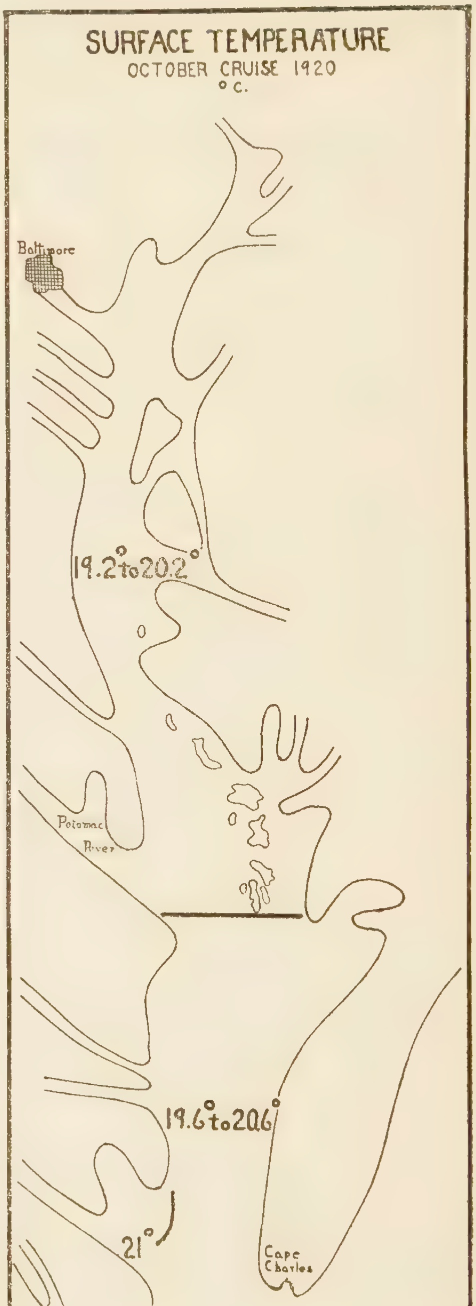
SURFACE TEMPERATURE
OCTOBER CRUISE 1920
°C.
Baltimore
19.2° to 20.2°
Potomac River
19.6° to 20.6°
21°
Cape Charles
Norfolk
Cape Henry

FIGURE 12

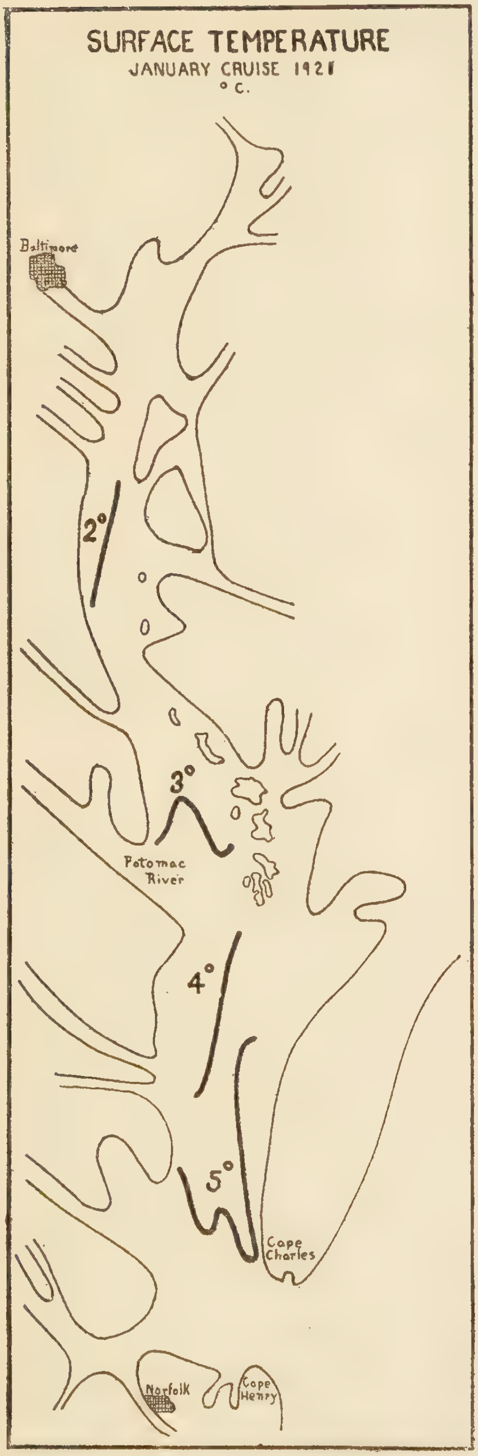
SURFACE TEMPERATURE
JANUARY CRUISE 1921
° C.
Baltimore
2°
3°
Potomac River
4°
5°
Cape Charles
Norfolk
Cape Henry

FIGURE 13

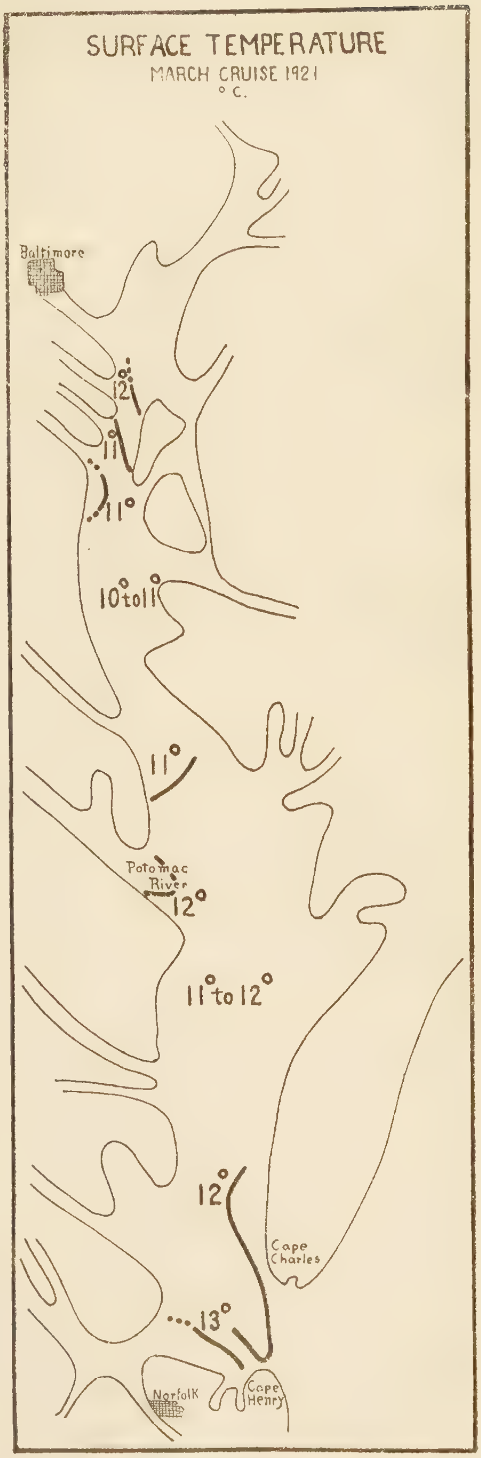
SURFACE TEMPERATURE
MARCH CRUISE 1921
° C.
Baltimore
12°
11°
11°
10° to 11°
11°
Potomac River
12°
11° to 12°
12°
13°
Cape Charles
Norfolk
Cape Henry

FIGURE 14

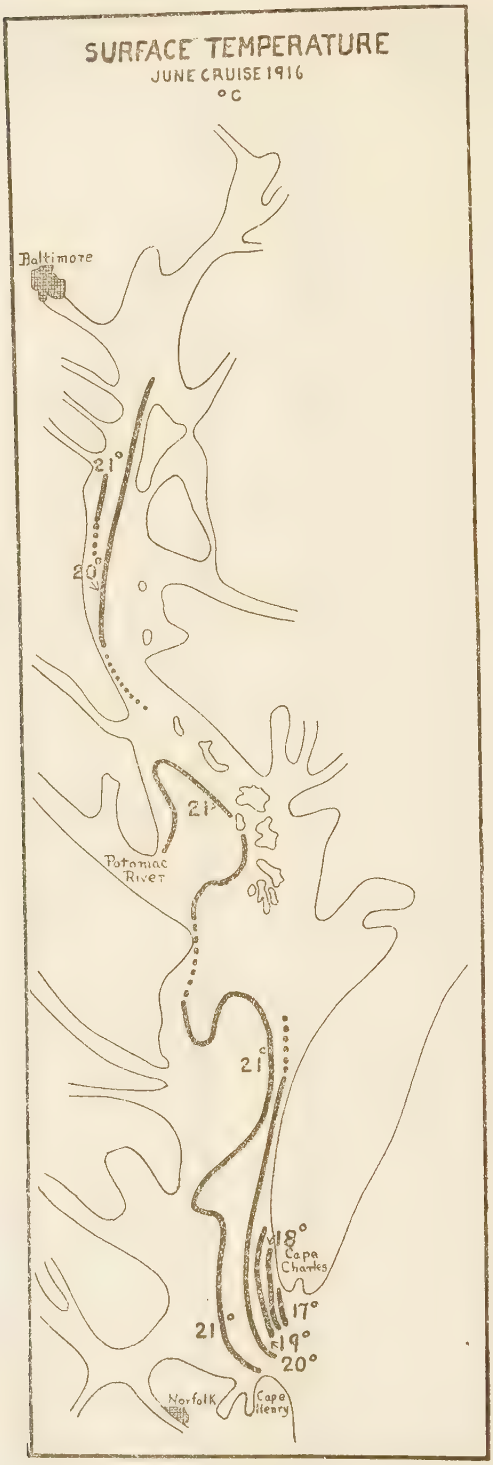
SURFACE TEMPERATURE
JUNE CRUISE 1916
°C
Baltimore
21°
20°
21°
Potomac River
21°
18°
Cape Charles
17°
21°
19°
20°
Norfolk
Cape Henry

FIGURE 15

VARIATION OF SURFACE TEMPERATURE ACROSS BAY

Referring to the map showing the surface temperatures for June, 1916 (fig. 15), one sees at once that the isotherms are arranged quite differently from those of August, 1920. Here we see a condition which is more characteristic of the warmer months. The isotherms, during this cruise at least, run, more or less, up and down the bay. This condition results from the warmer water being on the western side of the bay, except along the line *J*, *I*, *K*, and also from the fact that temperatures from north to south are close to uniformity.

After a study of the data for all the cruises it seems to be difficult to formulate any very definite rule for the distrubution of surface temperature with reference to the east and west sides of the bay. However, it may be stated that, judging from data collected during winter and summer cruises, warmer water lies decidedly more often at area *G* than at area *E*. These areas mark the line across the mouth of the bay.

BOTTOM TEMPERATURE AT MOUTH AND HEAD

The highest and lowest bottom temperatures for area *G* at the mouth of Chesapeake Bay, as recorded on our cruises, were 21.0° C. in July, 1916, and 3.6° C. in March, 1916, while at the head of the bay the highest and lowest temperatures at *U* were 24.4° C. in August, 1920, and 0.9° C. in January, 1921. It will be noted that the range was considerably less for the bottom water than for the surface water both at area *G* and at area *U* (surface 27.0° C. to 3.7° C. at *G* and 24.8° C. to 0.3° C. at *U*). A smaller range would be expected at the bottom, since that water is not subject so much to the effect of great changes in air temperatures.

DEEP-WATER TEMPERATURE FROM MOUTH TO HEAD

The decrease in water-temperature values passing from the line *D*, *C*, *B*, *A* just inside of the mouth of the bay to the region near Baltimore (this leaves out of consideration for the moment the region between *D*, *C*, *B*, *A* and *G*, *F*, *E*) was as marked for the deep water during the cruises of the colder months as for the surface water. This relation can be seen by inspection of the data for 20 and 30 meters. (See Tables 1, 2, and 4.) As in the case of the salinity, the data could not be collected simultaneously at all areas, but notwithstanding this they show consistently a decreasing range.

The greatest differences in deep-water temperature per unit of distance from mouth to head were found near the mouth of the bay between *D*, *C*, *B*, *A* and *G*, *F*, *E*, as in the case of the surface water. It was during the cruises of the warmest months of the year that the greatest range occurred. As examples, the difference in the bottom temperatures between *G* and *A* (21.0° C., 24.2° C.) or *G* and *D* (21.0° C., 25.5° C.) in July, 1916, *G* and *A* (15.5° C., 21.3° C.) or *G* and *D* (15.5° C., 24.0° C.) in August, 1920, and *G* and *A* (15.2° C., 17.1° C.) or *G* and *D* (15.2° C., 19.1° C.) in May, 1921, are of interest, especially those between *G* (the area through which most of the oceanic water enters) and *A*, where the bottom temperatures for *G*, at about 20 meters, are much lower even than those for *A* (about 43 meters). This condition supports the statement that the bottom water, as well as the surface water, entering the bay during the warmer months has a lower temperature than that inside of the bay.

Deep-water temperatures, as in the case of the surface temperatures, show almost invariably a decreasing range in the warmest months passing from *D*, *C*, *B*, *A* through *G*, *F*, *E* and an increasing range during the coldest months.

VARIATION OF BOTTOM TEMPERATURE ACROSS BAY

The temperature of the bottom water depends upon several factors, the most important of which are depth, presence of ice, inflow of water from the ocean, seasonal changes, and to some extent sudden changes in air temperatures. Our records show that on the summer cruises the coldest bottom water was found along the deep-water channel *G*, *A*, *H*, *J*, *L*, *R*, *S*, *X*, and *Y* and that on the winter cruises the bottom water of this channel was the warmest. Locally, at times during the autumn or winter and occasionally during the spring the temperature relations just mentioned were not so marked. The bottom temperatures along a line across the bay cutting the deep channel may show an approach to uniformity, notwithstanding large differences in depths. As examples, in the spring, during the March cruise, 1916, the bottom temperatures for *D* (5.5 meters), *C* (11 meters), *B* (12 meters), and *A* (40 meters) were 3.3° C., 3.3° C., 3.3° C., and 3.4° C., respectively, while in January, 1916, for the same areas the temperatures were 3.3° C., 3.9° C., 3.8° C., and 4.3° C. During the summer cruises, July, 1916, the bottom temperatures for *D* (6 meters), *C* (10 meters), *B* (12 meters), and *A* (42 meters) were 25.5° C., 24.9° C., 24.4° C., and 24.2° C.

VERTICAL DISTRIBUTION OF TEMPERATURE

The vertical distribution of temperature depends on many factors among which are: Seasonal, diurnal, and sudden local changes in air temperature sometimes accompanied by vertical circulation; strength and direction of the wind; relative thickness of fresh-water layers coming from the rivers and the more saline layers derived from the ocean; the relative temperatures of the fresh water and saline water layers; the cooling effect of the rain on both air and surface water (Krümmel, 1911); the decrease in temperature due to ice floes; and the depth of the water.

As might be expected, the greatest range in temperature from surface to bottom was found in the deep channel. Area *G*, at the mouth, showed the most extensive range—for example, in August, 1920, surface 27.0° C., bottom (23.6 meters) 15.5° C.; and in June, 1916, surface 20.5 ° C., bottom (22 meters) 10.7° C., a difference of 11.5° C. and 9.8° C., respectively.

An examination of the vertical temperature series shows that sudden breaks in temperature occur in the region of 10 to 20 meter depths. These changes are most clearly marked in the deeper parts of the bay and are most commonly observed when the water is stable or "harder" as Sandström (1919) describes it. Water in this condition shows layers of increasing density and usually increasing salinity passing from the surface to the bottom, and such a condition is characteristic of the warmer months of the year. A rather common summer condition for temperature, at least during the warmer part of the day, is that obersved at area *R* during June, 1921 (surface 20.0° C., 10 meters 20.0° C., 20 meters 15.5° C., 30 meters 15.3° C., 40 meters 15.3° C., 47.6 meters 15.1° C.). The layer showing the sudden decrease in temperature between 10 and 20 meters, which is evident in the series, is what is called the "Sprungschicht" by Richter (1891) and Krümmel (1911), "discontinuity layer" by Murray and Hjort (1912), "thermocline" by Birge (1898), and "transition zone" by Whippel (1914). This decline in temperature corresponds very definitely in depth with an increase in salinity. (Surface 11.20, 10 meters 11.68, 20 meters 19.42, 30 meters 19.66, 40 meters 19.80, 47.6 meters 19.78.) A similar relation between temperatures is often seen during the warmer months but frequently the correspondence in depth with the salinity increase is not so definite as in the case mentioned. Indeed, there is evidence indicating that the discontinuity in temperature may be disturbed by a drop in temperature due to rain, cloudiness, or other factors. As an example, in July, 1916, the surface temperatures at practically all stations on the bay were lower than those a few meters below, a condition which was not found usually during continued fair weather on the cruises of the summer months. At area *R* the temperatures were as follows: Surface 25.2° C., 8 meters 25.6° C., 16 meters 25.3° C., 26 meters 24.5° C., 36 meters 25.0° C., 46 meters 25.2° C. During June of the same year at area *R* a summer condition was found—for example, surface 20.3° C., 9 meters 19.3° C., 18 meters 17.7° C., 21 meters 17.6° C., 27 meters 17.2° C., 31 meters 17.0° C., and 41 meters 17.2° C. The records of the United States Weather Bureau show that during the July cruise there were heavy rains in regions about and on Chesapeake Bay. It seems highly probable that they account for the low surface temperatures. (See Krümmel, 1911.) An equally interesting cruise is that of August, 1920. Areas *G*, *F*, *A*, and *B*, near the mouth of the bay, were visited on August 22 and showed a very marked thermocline—for example, at *G*, surface 27.0° C., 10 meters 20.2° C., 20 meters 17.2° C., and 23.6 meters 15.5° C. Similar exceptionally high surface temperatures, even for summer months, were found at areas *F*, *A*, and *B*. This condition seems to be traceable to high air temperatures in that region. (Maximum at Norfolk 90° F. (32.2° C.) and minimum 68° F. (20.0° C.) on August 20.) Farther up the bay the air temperatures and the surface-water temperatures were much lower. (Maximum air temperature at Baltimore 70° F. (21.1° C.) and minimum 68° F. (20.0° C.) on August 20.) The thermocline was obliterated at practically every station and frequently the surface temperatures were lower than those a few meters below. Observations made at area *U*, near Baltimore, on August 26, showed, as an example, surface 23.5° C., 5 meters 24.4° C., 11 meters 24.2° C., at 12 noon. The night before these data were obtained the temperature at Baltimore had dropped to as low as 64° F. (17.8° C.) with a daytime maximum of 74° F. (23.3° C.), according to the records of the United States Weather Bureau. Several days of rainy weather in the region of Baltimore and Washington had preceded August 20, so it seems probable that the rain was also a factor in bringing about the lowered temperatures at the surface.

Ice floes have an effect on the distribution of temperature in the Chesapeake Bay. This was evident at area *U* during January, 1921. Observations were made of temperature and salinity at 1½-hour intervals for a good part of 24 hours, but toward the end of that period observations were discontinued on account of the floating ice which interfered with the instruments. Before the ice disturbed the work, the typical distribution of winter temperature was observed hour after hour—for example, at 4.05 a. m., surface 2.1° C., 5 meters 2.9° C., 11.9 meters 3.5° C. When the ice floes appeared at 5.35 a. m., however, a mesothermous distribution occurred as follows: Surface 0.3° C., 5 meters 1.6° C., 11.9 meters 0.9° C.

SEASONAL DISTRIBUTION OF WATER TEMPERATURE AND SALINITY

TEMPERATURE OF WATER DURING WINTER AND INFLUENCE OF OCEANIC WATER

The range of temperature values observed from the mouth of the bay toward the head varied with the season. A study of the winter data at the surface and at the 20 and 30 meter depths along the deep-water channel, areas *A*, *J*, *L*, *R*, *S*, *X*, *Y*, and *U*, shows a decreasing range with some irregularities from the mouth toward the head, as shown in Tables 1 and 4. The largest irregularities in the decreasing range of the 30-meter temperatures occur at areas *J* and *L*, which are close to the mouth of the

Potomac River. The reduced temperatures at these two areas are probably due to the large volume of colder, fresh water forcing its way in from the Potomac River, as seen in density profiles. Ordinary daily variations in air temperature should not cause the irregularities mentioned at 30 meters, but the surface water temperature would, of course, be affected by them.

Data for area *G*, which marks the main entrance into the bay, are included in the following discussion in order to show the influence of the oceanic water, although the depth at this area does not equal 30 meters (22 meters in January, 1916, 22.9 meters in January, 1921, and 23.8 meters in January, 1922). The data for area *S* in 1916 were obtained from a station near area *S*.

The decreasing range of temperature values from mouth to head shown in Table 1 may be ascribed to a difference in latitude, but there is evidence which indicates that the higher temperature at *G*, the deepest area in the mouth of the bay, is due, in part, to the entrance of warmer water from the ocean. The bottom reading at *G* during the January, 1916, cruise was 6.1° C. (22 meters), a temperature higher than that observed at any area or any depth in the bay during that cruise—considerably warmer even, than those at area *G′*, near Norfolk. The temperatures inside of the bay, then, show that the comparatively high bottom temperature at area *G*, in the mouth of the bay, has its origin from some other source. The data from the cruise of the U. S. S. *Roosevelt* off the mouth of Chesapeake Bay during January and February, 1916, (see Bigelow, 1917 b), show that the temperatures out to about the 20-meter contour were between 6° C. and 7° C. from the surface to the bottom, and that at the 200-meter contour they were considerably higher than nearer shore. These observations, however, were made about two weeks after the time the observations were made at *G*, but it is very probable that similar relations existed two weeks earlier. Temperatures of 10° C. and 12° C. were found over the continental slope—for example, in the region of the 200-meter contour. It is evident that there was a gradual increase in temperature at the surface and at depths from the shore outward; and it is practically certain that the warmer water at *G* had a higher temperature, owing to the fact that its origin was largely oceanic. It is through this area that the bulk of the salt water usually finds its way into the bay. At the time the temperature observations were made at *G*, the salinity at 22 meters was 32.57, the highest found on that cruise in the mouth or anywhere else in the bay. During January, 1921 and 1922, the highest bottom temperatures for the whole bay were found again at *G*, with the exception that in the latter year the temperatures at *F* equalled those at *G*. It is quite probable that the comparatively warm water of the ocean during the colder months of the year has a tendency to raise the temperature of the water of Chesapeake Bay. The temperature conditions at area *G*, the occurrence of water of fairly high salinity in the northern part of the bay, and the distribution of certain marine organisms are in keeping with this theory.

The vertical distribution of temperature during the winter cruises was found to be characterized by a low temperature at the surface and an increasing range from the surface downward (Katothermous, following Krümmel, 1911), as at area *G* in January, 1916, surface 4.1, 8 meters 4.9, 9 meters 5.6, 17 meters 5.8, 18 meters 5.9, 22 meters 6.1; and at area *R* during the same cruise, surface 1.1, 5 meters 1.2, 9 meters 2.2, 18 meters 3.4, 27 meters 3.6, 36 meters 3.8. A similar condition may be seen at area *G* in December, 1920, surface 10.5, 10 meters 10.8, 20 meters 11.3, 22.9 meters 11.6, and at many other areas. But there are times during the winter when close approaches to uniformity of water temperatures from surface to bottom occur. Such temperatures were observed during the month of January, 1921, which was an exceptionally mild month in Maryland at least. Ice floes were so common during the cruise in the upper part of the bay that they interfered with the instruments. The 24-hour current meter records at area *L* near the mouth of the Potomac River showed a dominating outgoing current from surface to bottom, which, however, was as usual of low velocity. The salinities were remarkably low at all depths for that time of the year, and at many areas there was, for such a body of water as Chesapeake Bay with its highly variable temperatures, a rather close approach to uniformity from the surface to the bottom. So there is much evidence to show that the bay had been flooded, probably gradually, with almost homothermous water of low salinity similar to that of the spring freshets. This condition combined with the freezing air temperatures, which occurred at the lower end of the bay during the January cruise (see U. S. Weather Bureau records for Norfolk, two days before our observations were made) and which chilled the upper layers, was undoubtedly largely responsible for the almost homothermous gradient from surface to bottom.

TEMPERATURE OF WATER DURING SPRING

The data collected on the spring cruise, as for the winter cruise, range decreasingly for the most part from the mouth toward the head. This is shown in Table 2, although it will be seen that there are some irregularities—for example, high surface temperatures at the upper end of the bay during March, 1922, and March-April, 1921, cruises. The temperature values for the bay were somewhat higher during three of the spring cruises, but in March, 1916, the readings, especially at the bottom, ran lower than during any of the winter cruises. According to the United States Weather Bureau this was an exceptionally cold March for Maryland. There was a remarkable unbroken period of low daily air temperatures recorded. The temperature observations made at *G* during the March cruise, 1916, were the highest observed in the whole bay, as was the case during the winter cruises, but in the data for the April, 1916, March, 1922, and March-April, 1921, cruises this relation was not so evident. Apparently during those months the change was taking place from the winter condition to that found during the summer cruises in which the bottom water temperatures at *G* were cooler than those observed at other areas in the bay.

The vertical distribution during the spring cruises varied like that of the winter season. On the March cruise of 1916—the exceptionally cold March—the temperatures showed a close approach to uniformity (homothermous), as at area *G* where the following readings were made: Surface 3.7, 5 meters 3.8, 10 meters 3.7, 20 meters 3.5, 22 meters 3.6. Occasionally the surface water was a little warmer than the intermediate layers, and below the latter the temperatures increased again (dictothermous), as during the March-April cruise, of 1921, at area *A:* Surface 12.1, 10 meters 11.2, 20 meters 11.3, 30 meters 11.4, and 42.5 meters 11.5—or as during the March cruise of 1922 at area *J:* Surface 8.1, 10 meters 6.2, 20 meters 6.2, 30 meters 6.5, 40 meters 6.2, 43 meters 6.6. Often on the March cruise and more often on the March-April cruise, however, the surface water was the warmest, and there was a decrease in temperatures passing downward (anothermous). In March, 1922, at area *G*, as an example, the temperatures were as follows: Surface 8.9, 10 meters 6.6, 24 meters 6.5; and at area *X*, surface 8.2, 10 meters 7.2, 20 meters 4.5, 26.5 meters 4.0.

TEMPERATURE OF WATER DURING SUMMER

It has been pointed out, under the section devoted to the surface temperature from mouth to head, that the distribution of the surface temperatures during the summer cruises was quite variable. There are indications that the surface temperatures may be much warmer at the southern end than at the northern, as when on August 21, 1920, the air temperatures were high at the lower end of the bay and low temperatures and rainy weather prevailed at the upper end, or warmer at the northern end than at the southern, as during the cruise of July, 1916. At the bottom there was evidence to show that the winter condition had been reversed, so that the coldest water was at the mouth of the bay. These conditions at 20 and 30 meters are illustrated in Table 3. It is clear that there was an increasing range of deep-water temperatures (as an example, at 20 meters) passing from *G* to *A*. On these cruises the lowest temperature observed in the whole bay was that at the bottom of area *G*, just the reverse of the condition existing in the winter, when the highest temperatures observed in the whole bay were at the bottom of the same area. Observations made outside of the bay at the beginning of the August cruise show that as far as the 200-meter contour, the temperatures (from 8° C. to 10° C. at all depths) were considerably lower than those of the bay and in a decreasing range as far as the 80-meter contour. Also, the temperatures at the surface were somewhat less than those of the surface of the bay.

During the summer cruises the surface water was found to be almost always the warmest, during the warmer part of the day at least, the temperature decreasing with the depth (anothermous), as in August, 1920, at *G*, surface 27.0, 10 meters 20.2, 20 meters 17.2, 23.6 meters 15.5; and at *R*, surface 24.2, 45.8 meters 23.9; or as in May, 1921, at *G*, surface 19.0, 10 meters 17.4, 22.8 meters 15.2, and at *R*, surface 20.0, 10 meters 20.0, 20 meters 15.5, 30 meters 15.3, 40 meters 15.3, 47.6 meters 15.1. The cruise of July, 1916, was made during a time when there was much rain and cloudy weather, and it had a marked effect on the vertical distribution of the temperature. At *A* the temperatures were as follows at 9 a. m.: Surface 24.3, 5 meters 24.9, 10 meters 24.6, 20 meters 24.1, 30 meters 23.9, 40 meters 24.1; and at *R*, surface 25.2, 5 meters 25.5, 10 meters 25.5, 20 meters 25.0, 30 meters 24.6, 40 meters 24.9, 46 meters 25.2 at 1.35 p. m. In general, all over the bay the surface temperatures were somewhat lower than those of the water a few meters below, and this condition was independent of the time of day.

TEMPERATURE OF WATER DURING FALL

During the cruise of September, 1916, the temperature values observed at the bottom (no data at 20 and 30 meters are available) showed an increasing range from the mouth northward as during the summer. No data were obtained at area *G* during that cruise, but at both *F* and *E*, which are areas in the mouth of the bay, the bottom temperatures were 22.8 at 13 meters and 22.2 at 16 meters, while the bottom temperatures for the following areas, marking regions of considerably greater depth even than those of *F* and *E*, were higher: *A* 23.4, *J* 24.6, *S* 24.8, *X* 24.8, and *Y* 24.8. During the cruise of October, 1920, the range of temperature values for 20 and 30 meter depths indicated that the summer condition was changing into that of the winter, while the data for the December, 1920, cruise indicated that this latter condition was established, the temperatures decreasing in range again from the mouth toward the head with the highest temperature in the whole bay at *D*. (Table 4.)

The cooler weather of fall brings with it a lowering of the temperature of the upper layers of Chesapeake waters, while those below, as pointed out by Hjort (1896) for Norwegian fjords, often retain their summer condition, thus resulting in a warmer layer being found between upper and lower cooler ones (mesothermous). Such a vertical range of temperatures was widespread over the bay during the cruise of September, 1916. This condition is well illustrated at area *A:* Surface 23.4, 7 meters 24.4, 14 meters 23.9, 22 meters 24.1, 32 meters 23.6, 42 meters 23.4; at area *J*, surface 24.1, 5 meters 25.0, 10 meters 24.7, 17 meters 24.6, 27 meters 24.6, 37 meters 24.6; and at area *X*, surface 23.9, 7 meters 24.9, 14 meters 25.0, 24 meters 24.8, 34 meters 24.8. According to the United States Weather Bureau, this was a decidedly cool September except during the first week. In fact, on the day the cruise was begun (September 8) the air temperatures at Baltimore, Washington, and Norfolk reached 94° F., 93° F., and 90° F. (34.4° C., 33.9° C., 32.2° C.), respectively, but a drop of 12, 5, and 4 degrees, respectively, occurred the next day and decreases in temperature continued for several days after that. On the other hand, October, 1920, was a warm month, and at the same areas the following readings were obtained: At area *A*, surface 20.4, 10 meters 20.1, 20 meters 20.0, 30 meters 19.4, 40 meters 19. 3, 44.8 meters 19.3; at area *J*, surface 20.0, 10 meters 19.8, 20 meters 19. 3, 30 meters 19.5, 40 meters 19.1, 43.0 meters 19.2; and at area *X*, surface 19.4, 10 meters 19.9, 27.5 meters 20.2. The lower bay, in general, showed a decreasing range of temperatures from the surface downward which would be in keeping with the high air temperatures. The surface temperatures, however, at *X* and at a few other areas, especially in the northern part of the bay, were found to be a little lower than those of the layers immediately below.

During the December cruise of this same year (1920) the autumnal condition had taken on the winter condition (katothermous), with a few exceptions.

SEASONAL DISCONTINUITY OF VERTICAL DISTRIBUTION OF TEMPERATURE

Under the section in which the vertical distribution of temperature from the surface to the bottom is discussed, it has been pointed out that the thermocline (discontinuity layer, Sprungschicht) is frequently seen in Chesapeake Bay and that at times its position coincides with a similar discontinuity in salinity. Such a condition has been noted in the Norwegian fjords, the Baltic Sea, and other localities. (See Krümmel, 1907, p. 395.) The thermocline is most marked during the warmer months, since it is the heat of the summer sun's rays that brings about the increase in temperature of the upper layer, thus separating it from the cooler mass of water below. During the cruises of April and June, 1916, the thermocline was evident at many areas on the bay. But such a condition is not necessarily limited to the warmest months, for during the cruise of March, 1922, when the waters were still cold, a distinct thermocline was noted. The data for areas *U*, *L*, and *G* are given in Table 7. At area *U* observations were made during the night as well as during the day and the temperatures were almost invariably higher at the surface than at 5 meters.

TABLE 7.—*Temperatures and salinities at various depths on March, 1922, cruise*

Date	Area	Temperature, ° C.	Salinity	Depth, meters
Mar. 29, 1922	U	9.0	5.22	0
		6.4	8.22	5
		5.0	10.33	11
Mar. 27, 1922	L	7.2	12.21	0
		5.8	14.54	10
		5.7	16.95	20
Mar. 27, 1922	L	5.6	17.12	30
		5.4	17.22	40
Mar. 25, 1922	G	8.9	18.36	0
		6.6	30.65	10
		6.5	31.10	24

On the other hand, during some of the midsummer cruises, such as July, 1916, and August, 1920, the thermocline was practically obliterated in the bay, owing to rain in the first case and cool weather in the second, aided probably by wind and currents. The records show, as would be expected, that the temperature of the upper layers drops during the night and rises during the day; but, independently of this, discontinuity layers occur corresponding to the warm and cold parts of the year and often in accordance with the origin of the upper and lower layers of water. On the August cruise the temperature and salinity data were as shown in Table 8.

TABLE 8.—*Temperatures and salinities at various depths on August, 1920, cruise*

Date	Area	Temperature, ° C.	Salinity	Depth, meters	Date	Area	Temperature, ° C.	Salinity	Depth, meters
August, 1920	U	23.5	4.75	0	August, 1920	L	25.0	19.76	30
		24.4	14.21	5			24.8	20.50	37
		24.2	15.21	11	Do	G	27.0	22.73	0
Do	L	25.5	13.72	0			20.2	29.05	10
		25.5	13.72	10			17.2	31.26	20
		25.5	13.77	20			15.5	31.74	23

It will be noted that the thermocline is conspicuous at *G*, the result of high air temperature in that region. Farther north, where the thermocline was not so evident or lacking, the air temperature was about 10° C. lower than in the region of *G*.

While the thermocline is more or less characteristic of the waters of Chesapeake Bay during the warmer months, a discontinuity in the degree of temperature and salinity often occurs during the winter. This condition is the reverse of that during the summer because there is an upper layer of water which is distinctly colder than the water below. This is most conspicuous along the deep-water channel. The fresher and lighter, although colder, water from the rivers lies over the much warmer but much heavier saline water having its origin from the ocean. Excellent examples of the discontinuity just mentioned occurred when the cruise of December, 1920, was made. Data for areas *U*, *L*, and *G* are shown in Table 9.

TABLE 9.—*Temperatures and salinities at various depths on December, 1920, cruise*

Date	Area	Temperature, ° C.	Salinity	Depth, meters	Date	Area	Temperature, ° C.	Salinity	Depth, meters
December, 1920	U	5.8	5.70	0	December, 1920	G	10.5	25.20	0
		5.9	6.02	5			10.8	28.76	10
		9.0	14.02	11			11.3	30.22	20
Do	L	8.7	15.03	0			11.6	30.96	22
		8.6	15.21	10					
		10.0	20.01	20					
		10.1	20.13	30					
		10.1	20.21	37					

DELAY IN SEASONAL CHANGE OF TEMPERATURE

The "Phasenverzug," a condition described by Krümmel (1907) in which there is a delay in the change of temperature of the bottom water, so that it does not reach its maximum temperature in midsummer but in the fall and does not reach its minimum temperature in the midwinter but in the spring, can not be said to be a fixed condition in Chesapeake Bay, such as it is in the English Channel according to Dickson (1893). The time of occurrence of maximum and minimum temperatures varies somewhat with the year. There are indications from the data obtained on our cruises that the minimum bottom temperature occurs sometimes in midwinter and sometimes in the early spring and that the maximum bottom temperature is attained at times in the late summer and at times in the autumn.

BACILLARIOPHYTA

DIATOMS

The indentifications of the diatoms found in the plankton of Chesapeake Bay have been made by Dr. J. J. Wolfe, and the original list may be found in a paper by Wolfe and Cunningham (1926). A considerable number of bottom diatoms stirred up by currents and semibottom diatoms are included. The discussion which follows is based on data tabulated by Doctor Cunningham.

GEOGRAPHICAL DISTRIBUTION

An examination of the list of diatoms with reference to the recorded distribution in other parts of the world shows that the various species mentioned may be classed as fresh water, brackish water, and marine diatoms. It is evident, judging from what is known of the distribution of marine diatoms in other regions, that those found in the bay include some neritic species (bottom or semibottom forms) which are not placed among the true planktonic forms, some which are considered to be true planktonic forms inhabiting coastal regions (neritic), and still others, also planktonic, which are spoken of as oceanic forms since they are ordinarily found outside of the coastal regions in the great ocean currents where the salinity is high. Furthermore, a glance at the list of neritic and oceanic species of diatoms shows that if we follow Cleve's (1897, 1901–02) grouping into arctic, temperate, and tropical forms all three groups are represented in Chesapeake Bay, although naturally the temperate forms are much in excess of the others. The grouping in the list given below is based on that of Cleve, but it has been modified to some extent in the light of the more recent work of Gran, Ostenfeld, Lemmermann, Karsten, Johnstone, Bigelow, and Fish. Unfortunately, our knowledge of the distribution of the various species of diatoms, even in the Atlantic Ocean, is still imperfect and the different groupings overlap one another to a considerable extent, so that the distribution given must be looked upon as tentative.

The following marine planktonic diatoms have been found in Chesapeake Bay. Species of Coscinodiscus and other species, concerning which there is confusion as to identification, have been left out. Those listed have been arranged according to their usually accepted distribution with reference to the arctic, temperate, and tropical regions of the Atlantic Ocean.

Neritic, Arctic: *Biddulphia aurita* (Lyngb.) Breb.

Neritic, Northerly Temperate: *Chaetoceras teres* Cl., *Leptocylindrus danicus* Cl., *Rhizosolenia setigera* Brightw., *Skeletonema costatum* (Grev.), *Thalassiothrix nitzschioides* Grun. Another form which may be included in this group but whose position is somewhat uncertain is *Nitzschia longissima* (Breb.) Ralfs.

Neritic, Southerly Temperate: *Biddulphia mobiliensis* (Bail), *Cerataulina bergonii* Perag., *Ditylium brightwellii* (West) Grun., *Eucampia zodiacus* Ehr., *Guinardia flaccida* (Castrac.) Perag. The following may be placed in this group, but their distribution is still uncertain: *Bacteriastrum varians* Lauder, *Bellerochea malleus* (Brightw.), *Lithodesmium undulatum* Ehr., *Rhizosolenia calcar avis* Schultze, *Rhizosolenia stolterfothii* Perag.

Neritic, Tropical: None.

Oceanic, Boreal Arctic: *Rhizsolenia semispina* Hensen,[7] *Chaetoceras decipiens* Cleve.

Oceanic, Temperate: *Rhizosolenia alata* Brightw., *R. styliformis* Brightw. The inclusion of the following species in this group is not as yet fully established: *Thalassiothrix frauenfeldii* Grun.

Oceanic, Tropical: *Planktoniella sol* (Brightw.) Schuett.

In addition to the true marine planktonic diatoms the following marine, bottom, or semibottom (tycopelagic) diatoms (Ostenfeld., 1913) occurred abundantly at times: *Actinoptychus undulatus* (Kuetz) Ralfs., *A. splendens* (Bail) Ralfs., *Donkinia recta* (Donk.) Grun., *Hyalodiscus stelliger* Bail., *Melosira sulcata* (Ehr.)[8] Kutz., *N. bombus* (Ehr.) Kutz., *N. cancellata* Donk., *N. humerosa* Breb., *N. smithii* Breb., *Pleurosigma affine* Grun., *P. fasciola* (Ehr.) W. Sm.

A few fresh-water or so-called brackish water forms were found and are here listed:

Asterionella formosa (Hass.), *Bacillaria paradoxa* Gmel., *Campylodiscus echeneis* Ehr., *Navicula borealis* (Ehr.) Kutz., *Nitzschia plana* W. Sm., *N. sigma* (Kutz) W. Sm., *Pleurosigma balticum* W. Sm., *Raphoneis amphiceros* Ehr.

Referring to the above list of those neritic species of marine, planktonic diatoms whose distribution in other regions is well established, we find the arctic, temperate, and tropical groups represented in Chesapeake Bay as follows: Arctic neritic, 1; northerly temperate neritic, 5; southerly temperate neritic, 5; tropical neritic, 0. Practically all the neritic diatoms belong to the temperate group. True tropical neritic diatoms have not been found, and only individuals of one species ordinarily classed as an Arctic form have been taken. This diatom, *Biddulphia aurita* (Lyngb.) Breb. was collected once in Chesapeake Bay during March, 1916, at area *A* in a surface sample. It was found to be common, according to Mann (1894), in deep-water dredgings off the mouth of Delaware Bay; it has occurred as an occasional species in Massachusetts Bay (April, 1913) according to Bigelow, and was common throughout most of the year 1916 (possibly 1915) in the Bay of Fundy according to Bailey (1917). Gran (1919) has found it a little farther north in the Gulf of St. Lawrence, and finally Cleve (1897) mentions it as occurring rarely in a few samples in Baffins Bay and Davis Straits.

The oceanic diatoms are distributed in regard to number of species in the different geographic groups as follows: Boreal, arctic oceanic, 2; temperate oceanic, 2; and tropical oceanic, 1.

Albert Mann (1894) has studied the diatoms dredged by the U. S. S. *Albatross* in 813 fathoms (1,487 meters) of water off the mouth of Delaware Bay, and has found a large number of species many of which are fresh-water forms characteristic of rivers in that latitude. He believes that they have been supplied largely by the Delaware River. In addition to these fresh-water forms, however, there are many marine forms, a few of which, as Mann says, may have been deposited there by the Gulf Stream. Those diatoms common to both regions are the following: *Navicula borealis* Ehrb., *Raphoneis amphiceros* E., *Actinoptychus undulatus* Ehrb., *A. splendens* Ralfs., *Melosira sulcata* Kz., *Navicula humerosa* Breb., *N. smithii* Breb., *Pleurosigma affine* Grun., *Biddulphia aurita* Lyngb., *Ditylum brightwellii* West., and *Rhizosolenia styliformis* Bright.

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[7] *Rhizosolenia hebetata var. semispina*, (Hensen).

[8] *Paralia sulcata* (Ehr.).

It is interesting to compare the species collected during 1915 and 1916 in Chesapeake Bay with the species observed by Fish (1925) at Woods Hole during 1923, although in comparing the two it must be remembered that collections at Woods Hole were made largely at the surface. However, Fish has found that the water at Woods Hole is thoroughly mixed owing to currents. Those marine planktonic species in common for the two regions, following Fish's grouping, are these:

Fresh and brackish water forms: None.

Semibottom forms: *Actinoptychus undulatus*, *Hyalodiscus stelliger.*

Neritic, Arctic: None.

Neritic, Northerly Temperate: *Chaetoceras teres*, *Leptocylindrus danicus*, *Nitzschia longissima*, *Rhizosolenia setigera*, *Skeletonema costatum*, *Thalassiothrix nitzschioides.*

Neritic, Southerly Temperate: *Bacteriastrum varians*, *Ceratulina bergonii*, *Ditylium brightwellii*, *Guinardia flaccida*, *Rhizosolenia calcar avis.*

Neritic, Tropical: *Bellerochea malleus.*

Oceanic, Boreal Arctic: *Chaetoceras decipiens*, *Rhizosolenia hebetata ver. semispina.*

Oceanic, Temperate: *Rhizosolenia alata f. genuina* (?), *Rhizosolenia styliformis*, *Thalassiothrix frauenfeldii.*

Oceanic, Tropical: None.

Here again, as in the case of the Chesapeake diatoms, a survey of the complete list of species as given in Fish's paper, with reference to the geographic groups in which they are usually placed, shows more temperate neritic forms than boreal arctic or tropical, and of these temperate forms the larger number belong to the southerly temperate neritic. The oceanic forms are much fewer in number than the neritic forms, a condition which is true of the Chesapeake collections. It should be noted, however, that the proportion of boreal arctic oceanic forms shows a considerable increase over what is found in Chesapeake Bay, and this is what should be expected. It is also in keeping with the fact that the colder currents from the northern regions which carry boreal arctic forms are of more importance in the latitude of Woods Hole than they are in the latitude of the mouth of Chesapeake Bay, where such currents have probably dipped below the Gulf Stream.

A study of Bigelow's (1914a, 1914b, 1915, 1917a) preliminary work on collections made in the Gulf of Maine, Massachusetts Bay, and the coastal waters between Maine and the mouth of the Chesapeake Bay show the preponderance of temperate neritic forms as is the case for Chesapeake Bay and Woods Hole, while the boreal arctic forms have assumed considerable importance among the oceanic diatoms as at Woods Hole.

Although Bailey's (1917) collections in the Bay of Fundy were made at a little higher latitude than those of Bigelow, not so many boreal arctic forms were found, although they were fairly well represented. His records cover collections made from January to October, inclusive, 1916 (?).

Still farther north the work of Gran (1919) in the Gulf of St. Lawrence and the oceanic regions outside of it shows the northerly forms replacing almost, if not entirely, the southerly forms. With the exception of four species which I have not been able to place with the literature at hand, the various species are grouped as follows: Arctic neritic, 9; boreal arctic neritic, 5; northerly temperate neritic, 3; arctic oceanic, 1 (?); boreal arctic oceanic, 5. Gran's collections were made during May, June and August, 1915.

SPRING AND FALL MAXIMA

It is evident from the study of the diatom counts of Wolfe and Cunningham that they were high during the April cruise of 1916 and the March cruise of 1920 in Chesapeake Bay. While this conclusion is not reached from counts made daily in any one locality, it is based on many samples collected on each cruise in 1915–16 and 1920–21. During 1915 the cruises were taken in October and December; during 1916 in January, March, April, June, July, and September; during 1920 in January, March, May, July, August, October, and December; during 1921 in January. The diatom counts were made on water samples collected at the surface and at or near the bottom. In addition, during 1915–16 counts were made of the individuals of each species at various depths. The results are expressed in the number ot diatoms per liter of water.

As an example, the diatom counts for area *A* at the surface were as follows: Year 1915, October, 4,300, December ——; year 1916, January 13,600, March 17,000, April 558,300, June 9,200, July 6,200, September 92,800. The counts at 27 meters were these: October 99,400, December ——, January 39,800, March 26,500, April 359,100, June 19,500. The maximum spring count was that of the April cruise both at the surface and at 27 meters, and there was a less marked rise in surface counts during the autumnal cruise. Autumnal records for 27 meters are lacking.

A similar surface series at area *A* for 1920 is the following: January 16,500, March 262,600, May ——, July 8,300, August 14,400, October 21,300, December 418,400. At the bottom these counts were found: January 19,700, March 229,400, May ——, July 27,000, August 32,800, October 3,100, December 43,600. Here again there was a markedly high count during the spring cruise of March and a fairly well-marked autumnal rise, which seems to have persisted into the winter months. The results of surface counts from area *A* are graphically shown in Figure 16.

High counts were found in all regions (although not at all areas) over the bay in March, 1920, and there were fairly widespread evidences of similar conditions during the April, 1916, cruise. An autumnal rise probably occurred all over the bay but not so markedly in the upper part. The records of the different cruises often show successive increases from early fall into midwinter, and the suspicion arises in one's mind as to whether the so-called autumnal rise is not the beginning of the spring maximum of the following year. As a matter of fact, data for 1915–16 and 1920–21 indicate that the autumnal maximum did not occur until very late and that there may have been a close approach of the two maxima to one another. The results in the Chesapeake are very similar to those observed by Steuer (1910) for the Adriatic Sea and by Fish (1925) for Vineyard Sound, etc.

SUMMER MINIMUM

The decrease in the number of diatoms during the summer cruises was about as marked as the increase for the vernal cruises; but occasionally, as has been observed by Gran in the Gulf of St. Lawrence, Fish at Woods Hole, Bigelow off Marthas Vineyard and others, rather large numbers occur locally in the summer months. A slight but distinct increase in diatom counts was found in the upper part of the bay during July, 1920. If these increases were due to specially favorable conditions of food supply in the bay, resulting from exceptional outflow from rivers, it is of interest to note that during the month previous the rainfall in Maryland and Delaware was one and one-third times the normal and that the summer was cool and wet, the wettest on record over southern Baltimore County.

DIATOM COUNTS AND MAXIMUM AND MINIMUM SALINITY

During 1916 and 1920 the salinity was high on the midwinter cruise—that is, January. The diatom counts for the same period were low. On the spring cruises, for example, April, 1916, and March, 1920, the salinity was much lower than in January. The diatom counts for these same periods reached the maximum for the year so far as our records show. During the summer cruises the salinity was a little higher and the diatom counts were markedly lower as a rule. In the autumn the data did not show clearly a correlation between lower salinities and the increased diatom counts known as the autumnal maximum. These relations may be seen in Figure 16, in which the diatom counts and salinities for surface water are shown graphically for area *A* during the cruises of 1915–16 and 1920. Similar conditions occurred at many areas, although often not as marked, especially in the upper part of the bay. Usually, however, the spring diatom maximum and the decrease in salinity at that time showed clearly. During the cruises of most of the year the numbers of diatoms were usually greater in the deep layers than at the surfaces, but at the time of the maxima, and especially the spring maximum, large numbers were

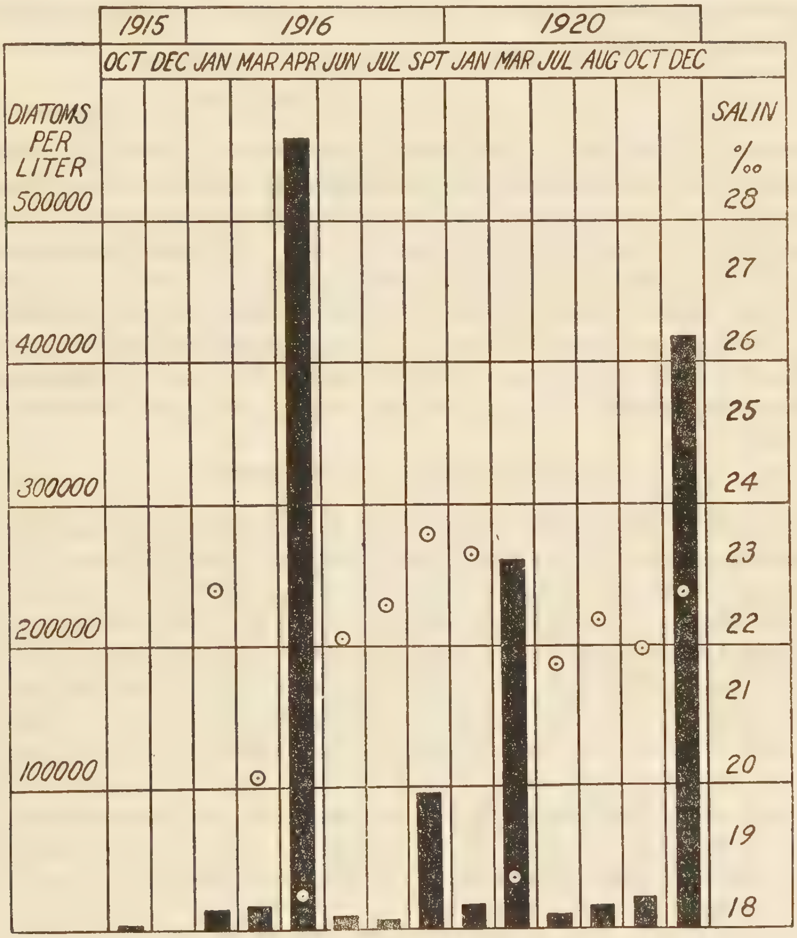

FIGURE 16.—Diatoms per liter of surface water at area A indicated by black columns. Salinity of water from which diatom samples were taken indicated by circles

found both at the surface and at the bottom and probably were present at intermediate depths. The larger number was sometimes at the surface and sometimes at the bottom.

It will be seen from Figure 16 that the highest counts for the spring cruises of 1916 were found in April and those for 1920 in March, but it must be noted that no samples were collected during April, 1920. Possibly, then, the maximum occurred in April, although we have no data to show it.

The records indicate clearly, so far as the surface and bottom samples are concerned, that the high diatom counts, especially those of the spring cruises, occurred generally at the time of low salinity, but it does not follow that the low salinity caused the large increase in diatoms.

DIATOM COUNTS AND HOMOHALINITY

An interesting relation is that between the vertical distribution of salinity and diatom counts. In many cases during 1920 when high diatom counts occurred there were unusually close approaches toward homohalinity from surface to bottom. Such a condition has been observed by Nathansohn (1909) for certain regions in the sea, by Gran (1912) for the waters southwest of Ireland, and by others more recently. This relation existed quite frequently during the spring cruise of March, 1920, but in 1916 this same condition was not so marked; in fact, usually the highest diatom counts were obtained on the April cruise while the nearest approach to homohalinity from the surface to the bottom, so far as we have records, occurred generally during the March cruise.

DIATOM COUNTS AT RIVER MOUTHS

The data which the survey has collected on the number of diatoms as a whole, not on separate species, do not supply any very convincing evidence for the theory that diatoms occur in greater abundance in the neighborhood of the mouths of rivers than at other places. Owing to the fact that quite a number of the diatom counts for the different areas along the western side of the bay were not made, a comparative study of the counts with reference to the river mouths on that side does not yield very satisfactory results. However, it may be seen from the surface data in Table 10 that, so far as our data go, the numbers were usually comparatively large at one or the other of the areas *P*, *J*, or *H*. These areas in the case of *P* and *J* are close to the mouth of the Potomac River and area *H* is near the entrance to the Rappahannock River. On the other hand, during the March cruise while the counts were high at area *P* near the mouth of the Potomac River they were even higher farther up the bay.

TABLE 10.—*Diatom counts in surface samples on west side of bay, per liter*

Area	1920							1921
	January	March	May	July	August	October	December	January
D	14,700	(1)	(2)	7,400	900	5,700	28,300	(2)
H	7,400	86,300	269,100	7,800	3,700	3,200	31,300	36,300
J	243,100	(2)	593,700	3,400	3,900	10,600	13,400	29,000
P	11,100	465,400	507,300	105,800	4,900	(2)	5,700	11,800
R'	(2)	690,100	(2)	14,100	(2)	3,900	(2)	(2)
T	4,600	769,200	(2)	9,900	1,000	(2)	(2)	12,200

[1] No sample.

[2] No count.

The highest diatom count for all of the cruises of the year 1920 was 1,563,000, and this was found in March, 1920, at area *L* close to the mouth of the Potomac and at the bottom. On the other hand, the second largest count, 1,055,400, was found at area *B* in a sample taken at the bottom in March, 1920. This area is situated close to one of the deepest holes in the bay and near Cape Charles City, which is located on the shore of the bay within a few hundred yards of the area.

The evidence in support of the theory that the highest diatom counts are to be found in the neighborhood of the mouths of rivers is not conclusive, and yet there are indications that there may be such a relation. Undoubtedly a study of the distribution of each species of diatom rather than a mixture of fresh-water, semi-bottom, and marine diatoms, such as is found in total diatom counts, would be more satisfactory. Some of the evidence we have from this source will now be mentioned. It will be discussed later.

The data concerning the abundance of the different species of diatoms at surface, bottom, and uniform intermediate depths are limited to the cruise taken in October, 1925. One species, *Skeletonema costatum*, which lives as a littoral-bottom form to some extent but which also exists as a widely distributed plankton form in Chesapeake Bay, is of interest in this connection. It will be shown later under the section in which the distribution of *S. costatum* with reference to hydrographic data is discussed that this diatom during the cruise of October, 1915, was more abundant, except at 27 meters, in the region of the mouth of the Potomac River than at any areas investigated.

DIATOM SCARCITY AT MOUTH OF BAY

The diatom counts in the mouth of the bay were usually comparatively small. Such a condition might be expected, since it is a shallow region with a shifting bottom which at times is scoured by rather rapid currents. It is a well-established fact that such places are not favorable for the development of diatoms. The highest count recorded in the mouth of the bay during the years 1916 and 1920 was a surface count of 438,800. This number was found at area *F* during April, 1916, along the line *E*, *F*, *G*, which extends across the mouth of the bay. Even at this time, which was during the spring maximum, there were higher counts along the line *A*, *B*, *C*, *D*, which runs from Cape Charles City to New Point Comfort. The records show 558,300 (surface) at *A* and 3,157,200 (bottom) at *D*.

RELATION OF DISTRIBUTION OF DIATOMS TO SALINITY

It is well established from a study of geographical distribution that certain diatoms (oceanic) are characteristic of waters of high salinity, such as that of the open ocean; that others (neritic) are characteristic of waters of lower salinity found along the sea coast and in estuaries; and that still different ones frequent the fresh waters or rivers emptying into the ocean. But, also, it is well known that many of these diatoms are able to stand a large range of salinities and that oceanic as well as neritic diatoms are often found in estuaries where the salinity is very low. The assumption is that the oceanic forms as well as neritic forms are brought in with the currents from the ocean, but it is known that resting spores are formed in the latter type. It is believed by many investigators, especially by Gran, that these spores settle to the bottom of the estuaries and periodically assume the floating condition, so that there are supplies from year to year of certain neritic species which arise locally.

The degree of dependence of diatoms on the salinity of the water has long been an unsettled question. Naturally, one would seek for light on the subject in regions where there is a distinct stratification with reference to salinity—that is, where there are considerably fresher layers overlying much more saline layers. The Baltic Sea, which is flooded now and then by saline water from the ocean and by fresh water from rivers; the Arctic and Antarctic Oceans, which have a surface layer of fresher water arising from the melting polar ice; estuaries such as are found in England; the fjords of Norway and Sweden; and finally the mouths of large rivers where fresh water and saline water meet one another, have been investigated by ascertaining the salinity at various depths from surface to bottom, together with the diatom counts at the same depths. If there is a horizontal distribution of diatoms with reference to salinity as indicated by geographical studies, one would expect a vertical distribution correlated to some extent with the salinity gradient from surface to bottom. But the problem is complicated by other possible factors—differences in temperature, light intensity, and amount of nutriment at various levels, with the accompanying reactions to these differences. Also water currents produced in various ways often tend to disturb the relation which the diatoms might usually bear toward salinity.

However, some investigators have found the number varying with the salinity in regions where the temperature and light did not seem to be controlling factors. Apstein (1906), in his studies of the waters of the Baltic Sea, discovered that many Chaetoceras, Rhizosolenia, Cerataulina, and Guinardia species of diatoms occurred only on the western side of the Baltic where the salinity was more than 15 per mille while *Chaetoceras danicum* and *bottnicum* were confined mainly to the east side, where the salinity was much weaker. Büse (1915) found the currents entering Kiel Bay from the west generally richer in diatoms and of a higher salinity than those coming from the east.

One would look for such relations near the mouth of Chesapeake Bay, as, for example, along the line made by areas *A*, *B*, *C*, *D*. At *D* on the west side of the bay, the fresher water is found, while at area *A* on the east side, where the depth is much greater, the more saline water of the ocean finds its way. The numbers of individuals of different neritic and oceanic species should be compared with the salinities at these areas. Unfortunately, the data on separate species are insufficient for such a comparison. Total diatom counts, however, at the surface for these two areas as compared with the salinities are of interest.

TABLE 11.—*Surface diatom counts and salinity for 1920*

Area	January		July		August		October		December	
	Diatoms	Salinity	Diatoms	Salinity	Diatoms	Salinity	Diatoms	Salinity	Diatoms	Salinity
A	16, 500	23. 32	8, 300	21. 72	14, 400	22. 36	21, 300	21. 99	418, 400	22. 78
D	14, 700	19. 74	7, 400	17. 28	900	19. 48	5, 700	17. 31	28, 300	21. 51

It is clear from data obtained for the cruises of January, July, August, October, and December during 1920 that the more saline surface water along the line *A*, *B*, *C*, *D* was found on the eastern side of the bay—that is, at area *A*. The total surface diatom counts were higher, on each cruise, at area *A* than at area *D*, which is on the west side of the bay. While the various species making up these total counts have not been identified, it is safe to say that the counts include fresh-water, neritic, oceanic, and semibottom diatoms. We have no data to show that the higher counts at area *A*, where the water was most saline, were due mainly to neritic and oceanic diatoms carried in at the time from the ocean and consequently adapted to a sea water of higher salinity. It is possible also that some of the neritic forms were produced locally from resting spores. Furthermore, the differences may be due to differences in nutritive value of the water or to other factors. Occasional surface counts made at areas *B* and *C*, especially during the spring maximum, did not always support the relation pointed out above. Deep-water counts were not made at equivalent depths on the east and west sides of the bay, so they are useless in this connection.

COMPARISON OF DIATOM COUNTS AT MOUTH AND INSIDE THE BAY

A comparison of the diatom counts found along the line *E*, *F*, *G*, in the mouth of the bay, with those along the line *A*, *B*, *C*, *D*, which runs from Cape Charles City to New Point Comfort, farther inside the bay, would be of interest in order to see if the numbers are higher in the mouth of the bay during the autumn and winter cruises when, as a rule, the salinities are higher, the incoming current is more dominant, and the Gulf Stream Eddy (Atlantic gyral) is shifting in a northerly direction. At such a time one might expect larger numbers at the mouth, if the bay receives any considerable supply of diatoms from the outside. Only during March, 1916, and January, 1920 which were months of high salinity, have higher counts been found along the line *E*, *F*, *G*, than along *A*, *B*, *C*, *D*. The differences were small and the data too meager for a satisfactory comparison. It is true that the oceanic diatoms (see the section on the relation of distribution of species to the hydrographic data) which can be taken as an indication of the influx of oceanic water have been found almost exclusively during the months when water of higher salinity was making its way into the bay, yet the lack of diatom counts for some of the areas along the lines *E*, *F*, *G* and *A*, *B*, *C*, *D* on every cruise, the absence of data on the species found, and the rather limited current data from 24-hour stations make further work necessary before any definite conclusions may be reached.

The Atlantic water that enters the bay, judging from our salinity data, is not pure oceanic water. Salpa, which is commonly found in the oceanic water of the Gulf Stream off the mouth of Chesapeake Bay, has not been found in the bay, and true oceanic diatoms during 1916 at least were scarce.

RELATION OF DISTRIBUTION OF SPECIES TO HYDROGRAPHIC DATA

The data on the number of individuals of each species are limited to the cruises of October and December, 1915, and January, March, April, June, July, and September, 1916. During October, 1915, counts were made for each species of diatom from the surface to the bottom at 9-meter intervals for areas *A*, *J*, *L*, and *R*. Counts were made also at many other areas during the cruises for 1916, but there was considerable irregularity in the choice of areas and the number of samples. However, the depths at which samples were taken were practically without exception at 0, 9, 18, or 27 meters, thus corresponding with those for October, 1915. Almost invariably only two counts were made for each species at each area during 1916—a surface count and one at 9, 18, or 27 meters, depending on the depth at the area.

The fresh-water diatoms in the plankton were not abundant at the areas visited in Chesapeake Bay. This was expected, since usually the water at all these areas was brackish in character. *Asterionella formosa* (Hass.), the tests of which occurred so commonly in oceanic bottom deposits off the mouth of the Delaware River according to Mann (1894), were found only here and there in small numbers but widely distributed over Chesapeake Bay. The highest counts were obtained during the colder months and at areas near the mouth of the bay. *Navicula borealis* (Ehr.) Kutz, also mentioned by Mann, and *Bacillaria paradoxa* Gmel. (now called *Nitzschia paradoxa* Gmel.) occurred about as abundantly as *A. formosa*, but they were less widely distributed. *Campylodiscus echeneis* Ehr. was taken in very small numbers in the lower half of the bay. Most, if not all, of these forms are littoral also (Gran, 1908).

The so-called brackish water diatoms were represented in largest number by *Raphoneis amphiceros* Ehr.—a form found frequently in deposits off the mouth of the Delaware River by Mann. It was taken only in the southern half of the bay. Another brackish-water form, *Nitzschia sigma* (Kutz) W. Sm., designated by Mann as "frequent" was found widely distributed over Chesapeake Bay but in every small numbers. *Nitzschia plana* W. Sm. and *Pleurosigma balticum* W. Sm. were very scarce, the former occurring only in the lower half of the bay and the latter only at area *A* near the mouth.

The bottom and semibottom (tychopelagic) diatoms are abundantly represented in Chesapeake Bay. A form which is closely related to the tychopelagic group (classed above in the neritic northerly temperate group) is *Skeletonema costatum* (Greve) which according to Ostenfeld (1913) is found all the year round as a littoral-bottom form in European waters. It was very abundant and very widely distributed in Chesapeake Bay during the cruises of 1915 and 1916. It is known to be largely independent of the degree of salinity, and so its occurrence in considerable numbers at area *X*, almost as far north as Annapolis, is not surprising. As we shall see, its behavior is not that of a bottom form, for the highest counts, judging from the data for the cruise of October, 1915, are not at the bottom. The condition just mentioned is in keeping with Ostenfeld's statement that this species multiplies to an important degree in the plankton. *Skeletonema costatum* was found in the plankton samples during all the cruises from October, 1915, to September, 1916.

The highest counts were obtained during the October and January cruises, the numbers decreasing during the spring cruises until April, when the maximum was reached. This and similar conclusions for other forms as to the maximum and minimum occurrence is based mainly on a surface and a deep-water count for each area, but such counts were made at nine widely distributed areas on each cruise.

Ostenfeld and others have pointed out that *Skeletonema costatum* is extremely euryhaline—that is, adapted to a great range of salinity. In Chesapeake Bay it has been found in waters from 11.13 to 32.00 per mille. The range of temperatures, 1.0° to 26.1° C. is about as extreme as that of the salinities.

During the cruise of October, 1915, when the largest numbers were found for *Skeletonema costatum*, there was evidence to show that the highest counts were near the mouth of the Potomac River. The surface counts were as follows: Area *A*, 900; *J*, 4,300; *M*, 1,800; an unlettered area near the middle of the Maryland and Virginia line directly in front of the mouth of the Potomac River, 35,800; *L*, 4,200; *P*, 28,500; and *R*, 25,800. At 9 meters the counts for the same areas were these: Area *A*, 200; *J*, 6,700; *M*, no count; the unlettered area, 26,600; *L*, 10,500; *P*, 33,300; and *R*, 5,700. At 18 meters the following counts were obtained: Area *A*, 1,400; *J*, 13,200; *M*, 34,100; the unlettered area, no count, not 18 meters deep; *L*, 2,100; *P*, too shallow; and *R*, 2,600. It will be seen that at 0, 9, and 18 meter depths the highest counts were close to the mouth of the Potomac River. On the other hand, at 27 meters the highest was at area, *A*; but at 36 meters, again, the highest count was near the entrance of the Potomac: Area *A*, 700; *J*, 9,500; *M*, too shallow; the unlettered area, too shallow; *L*, 7,500; *P*, too shallow; *R*, 900. The largest count for any area at any depth during the October cruise was 35,800, a surface count directly in front of the mouth of the Potomac; and the second largest count, 34,100, was one at 18 meters on area M in the middle of the mouth of the Potomac. Again in December, 1915, the highest surface count, 15,100, was at area *J* and the largest deep-water count, 22,800, was at area *P*. Both of these areas are very close to the mouth of the Potomac River. It must be mentioned, however, that the counts for December are much fewer in number than those for October. The data for the rest of the cruises are insufficient for purposes of comparison.

The vertical distribution of *Skeletonema costatum* during October, 1915, seems to have been largely independent of the degree of salinity, although, as a general rule, the highest counts were below the surface and above the bottom. A very interesting comparison of the vertical distribution of this diatom at areas *A*, *J*, *L*, and *R* during October may be seen in Table 12. The samples for *A* (near Cape Charles City) were collected on October 22 from 3 to 4 p. m.; those for *J* (a little south of the mouth of the Potomac) on October 24 from 10.30 to 12 noon; those for *L* (a short distance north of the mouth of the Potomac) on October 25 from 9.49 to 10.38 a. m.; and those for *R* (about half way up the bay) on the same date from 1.50 to 3.08 p. m. It will be seen that the highest count for area *A* was in deep water, 27 meters; for *J* at shallower depth, 18 meters; for *L*, at 9 meters; and for *R* at the surface.

TABLE 12.—*Skeletonema costatum, October, 1915*

Meters	A	J	L	R	Meters	A	J	L	R
0	900	4, 300	4, 200	25, 800	27	10, 400	100	4, 400	700
9	200	6, 700	10, 500	5, 700	36	700	9, 500	7, 500	900
18	1, 400	13, 200	2, 100	2, 600	46	800			1, 300

A similar condition, although not so marked, was seen for some other neritic diatoms collected at the same time. The true bottom forms, on the other hand, which do not multiply to any extent in the plankton, did not show the vertical distribution just mentioned. It is not permissible to draw any definite conclusions as to the factors involved in bringing about the vertical distribution of *Skeletonema costatum* during the October cruise, especially since no counts approaching these in completeness were made during any other cruises, but it may be mentioned that during the time from October 21 to 25 the air temperature at Baltimore and Washington, according to the United States Weather Bureau, dropped from 64° F. (17.8° C.) to 42° F. (5.6° C.) and 37° F. (2.8° C.), respectively. One might suspect that there had been an increase in the viscosity of the water in the northern part of the bay due to the large drop in air temperature, which resulted in a greater buoyancy of the water and an upward movement of the diatoms. If such a movement toward the surface actually occurred at area *R*, and to a lesser degree at *L* and *J*, we have no evidence to show that it was in response to differences in the turbidity of the water, to differences in food conditions, nor to differences in the intensity of the sunlight shining on the surface. Concerning the last possible factor, however, the ship's log showed that the sky was clear when the samples were taken at areas *J*, *L*, and *R*. Whatever conditions gave rise to the vertical distribution mentioned during the October cruise of 1915, it seems probable that they were peculiar to that cruise, for such a distribution is not even suggested from an examination of the data from other cruises.

Paralia sulcata (Ehr.), a tychopelagic diatom listed by Wolfe and Cunningham as *Melosira sulcata* (Ehr.) Kutz, was widely distributed in Chesapeake Bay during 1916 and was present at least as late as September in considerable numbers. It was found even as far north as area *X* during every cruise except September in 1916, and it was present in waters of a great range of salinities and temperatures.

The highest counts obtained both at the surface and in deep water were during the March and April cruises. As examples, the surface counts at area *A* were as follows: January, 2,600; March, 4,200; April, *7,700*, June, 0; July, 100; and September, 1,000. At 27 meters the counts were: January, 4,900; March, *6,700;* April, 4,800; June, 2,400; July, no count; and September, no count. For area *J* the surface counts were the following: January, 500; March, *2,400*; April, 1,100; June, 500; July, 200; and September, 200. At 27 meters: January, 3,900, March, no count; April, *15,200*; June, 500; July, no count; September, 400.

Again, as in the case of *Skeletonema costatum*, the highest counts were found close to the mouth of the Potomac River, 15,200 at 27 meters and 15,800 at 26 meters for areas *J* and *L*, respectively, during April. These counts are about double those of any other counts during the year for this species.

This diatom, which has a comparatively heavy test, has the vertical distribution of a typical bottom form. The counts of *Paralia sulcata* showed the highest numbers, with one exception, at the bottom; the numbers gradually decreasing toward the surface. Data from other cruises, although limited to a surface and a deep-water count, showed the highest numbers in deep water with only a few exceptions—namely, in very shallow regions and during the spring maximum, when the water is in an unstable condition.

Table 13 gives the counts for *Paralia sulcata* found in the same samples from which the counts for *Skeletonema costatum* tabulated above were made, so the salinity, temperature, and other environmental conditions were the same for both.

TABLE 13.—*Paralia sulcata, October, 1915*

Meters	A	J	L	R	Meters	A	J	L	R
0	--------	700	500	700	27	800	1,200	1,600	3,400
9	500	--------	300	--------	36	1,400	2,100	4,700	1,400
18	700	3,600	600	2,600	46	4,800	--------	--------	4,800

Another common diatom in Chesapeake Bay during 1916 which is not a true plankton form is *Pleurosigma affine* Grun. It was widely distributed through the bay from the mouth to the region of Annapolis and occurred in the plankton during all the cruises—that is, January, March, April, June, July, and September. In addition to this it was present during October and December in 1915. The highest counts were found during October, January, and April, and most of these were from areas near the mouth of the Potomac River. The highest count for all cruises was at area *M*, in the mouth of the Potomac at 18 meters. The numbers of this diatom usually increase from the surface to the bottom. It seems to be a bottom form which is easily disturbed from its resting place.

The following tychopelagic forms were widely distributed in the bay but the counts made were not large: *Actinoptychus undulatus* (Kuetz) Ralfs., *Hyalodiscus stelliger* Bail., *Navicula bombus* (Ehr.) Kutz., *N. cancellata* Donk. Other tychopelagic forms occurred in very small numbers and had a very limited distribution in the plankton so far as the data for 1916 show. *Actinoptychus splendens* (Bail.) Ralfs. was found near the mouth of the bay only at areas *A*, *G*, and *F* and *Donkinia recta* at area *G* only.

The neritic arctic group is represented by one species, *Biddulphia aurita* (Lyngb.) Breb. While it was found to be common in bottom samples off the mouth of the Delaware River by Mann, it was collected from the plankton on one occasion only in Chesapeake Bay during the year 1916. It was in a surface sample at area *A* near the mouth of the bay. The sample was taken during the month of March in water of 3.1° C. temperature and 24.14 salinity.

Of those diatoms which have been included under the neritic north temperate group only two species, *Rhizosolenia setigera* Brightw. and *Skeletonema costatum* (Grev.), were widely distributed in Chesapeake Bay. The records for *R. setigera* show that it occurred most abundantly from the mouth of the Potomac River to the mouth of the bay, and that the highest counts were obtained during the autumn and spring cruises (October, 1915, and April, 1916), indicating autumn and spring maxima. The counts in the region of the mouth of the Potomac were not any larger than those lower down the bay at area *A*. The distribution of this species in the Chesapeake shows that it can stand considerable variation in salinity and temperature, but it is of interest to note that above the mouth of the Potomac it was not recorded as having occurred in the surface layer. The data are not complete enough to admit of any conclusions as to the vertical distribution. A discussion of the distribution of *S. costatum* has been taken up above. Other species included in the neritic northerly temperate group—namely, *Thalassiothrix nitzschioides* Grun., *Nitzschia longissima* (Breb.) Ralfs., *Chaetoceras teres* Cl. and *Leptocylindrus danicus* Cl.—were not represented by large numbers in the bay, although *T. nitzschioides* was found as far north as area *R* in October (16.49 per mille, 17.3° C.) and *N. longissima* as far north as the same area in June (approximately 17.00 per mille, 17.2° C.).

The most abundant diatom of the neritic southerly temperate group during the 1915 and 1916 cruises was *Cerataulina bergonii* Perag. The high counts of the April, 1916, cruise at areas *A*, *J*, *L*, and *X* as compared with the numbers found on other cruises indicate a marked spring maximum. The minimum occurred in the summer, judging from the surface records of the July cruise. At area *A* during the April cruise the surface count was 407,200 (18.46 per mille, 11.4° C.), at *J*, 65,400 (10.81 per mille, 12.1° C.); at *L*, 40,400 (12.05 per mille, 11.0° C.); and at *X*, 5,200 (5.88 per mille, 9.4° C.). The deep-water count for *A* at 27 meters was 300,800 (no salinity record, 10.5° C.); for *J* at 27 meters, 353,800 (no salinity record, 8.8° C.); and for *L* at 26 meters, 173,200 (17.63 per mille, 8.9° C.). No deep-water count was made at *X*. It is evident from the records that the largest numbers of *C. bergonii* were found in samples from the lower half of the bay, especially at area *A* and the areas near the mouth of the Potomac River. The records for this diatom and those which follow are insufficient for a consideration of the vertical distribution. *Rhizosolenia calcar avis* Schultze, which I have placed provisionally in the neritic southerly temperate group but which is sometimes included among the neritic tropical forms, does not seem to have been taken at all by Bailey, Fritz, Gran, Mann, or Cleve in more northern waters. It occurred in fairly large numbers in Chesapeake Bay during the year 1916 and was widely distributed over the bay. At area *A*, near the mouth of the bay, it was taken on the cruises of October, 1915, January, March, April, June, July, and September, 1916; in other words during all the cruises except December, 1915. Farther up the bay it was recorded also during December. The highest counts were obtained during the April cruise and the smallest during the July cruise. The two largest counts were those of area *J*, 6,400 at 27 meters (estimated at 18.00 per mille, 8.8° C.), and of area *L*, 6,500 at 26 meters (17.63 per mille, 8.9° C.), during the April cruise. It will be noted that both areas mentioned are close to the mouth of the Potomac River. This form was found as far north as area *X* on the cruises of December, 1915, January, March, and September, 1916, when the salinity was comparatively high for that region. During the January cruise the surface count was 100 (11.13 per mille, 1.0° C.), and that at 28 meters, 3,000 (17.00 per mille, 3.6° C.). The wide distribution of this diatom in Chesapeake Bay, its occurrence there during a large part of the year, and the fairly large numbers during the spring maximum in the region of the mouth of the Potomac River are conditions which favor its inclusion under the neritic group, where Cleve, Ostenfeld, and Fish have placed it, rather than under the oceanic group to which it has been assigned by Gran (1908).

Rhizosolenia stolterfothii was found as far north as area *X*, in very small numbers on the cruise of June, 1916. During the winter cruises (December, 1915, January, 1916) and even on the March cruise this form was almost absent from the plankton; but in April it was very abundant at two areas under the following conditions: Area *G*, surface 126,000 (21.92 per mille, 11.1° C.), 18 meters 52,000 (29.78 per mille, 7.0° C.); area *P*, surface 49,800 (11.98 per mille, 10.3° C.), 11 meters 11,400 (12.12 per mille, 10.6° C.). At other areas there were no records of its occurrence in April. During the summer cruises (June and July) the counts were small, but in September large numbers were found at area *F*, surface 35,900 (27.54 per mille, 22.5° C.) and area *A*, surface 79,000 (23.59 per mille, 23.4° C.). This species was evidently widely distributed over the bay but in small numbers except in the lower half, where it was most abundant near the mouth (areas *A*, *F*, *G*). As in the case of *Skeletonema costatum*, the largest counts were obtained at 27 meters for area *A*, at 9 meters for area *L* and at the surface for area *R* during the October cruise of 1915. The records for the remaining diatoms included in the neritic southerly temperate group indicate that they did not flourish in Chesapeake Bay, at least during the year 1916, that they occurred in largest numbers near the mouth of the bay, and that the counts near the mouth of the Potomac River were not conspicuously large. There is some indication that *Guinardia flaccida* (Castrac.) Perg., *Biddulphia mobiliensis* (Bail.), and *Bellerochea malleus* (Brightw.) have maxima in the autumn and the spring. The data for *Ditylium brightwellii* (West) Grun., *Eucampia zodiacus* Ehr., *Lithodesmium undulatum* Ehr., and *Bacteriastrum varians* Lauder are so meager that it is unjustifiable to discuss them in detail.

No neritic tropical forms were found in Chesapeake Bay unless *Bellerochea malleus* and *Rhizosolenia calcar avis*, which I have included provisionally in the neritic south temperate group, are considered as tropical forms.

The oceanic diatoms were not abundantly represented in Chesapeake Bay during 1916—a condition which should be expected, since pure oceanic water, so far as our records show, did not have access to it. There was no marked maximum for these forms during April such as was characteristic for many neritic forms, and in most cases their occurrence was confined to the late summer, fall, winter, and early spring, when the salinity was highest near the mouth of the bay. Whether such a condition can be related without question to the shifting of the highly saline North Equatorial Stream (Johnstone, 1923) toward the north during late summer and early fall must remain a subject for further investigation.

Two species belonging to the oceanic, boreal, Arctic group have been found: *Chaetoceras decipiens* Cleve and *Rhizosolenia semispina* Hensen. The former, which is such a common form in the North Atlantic Ocean, but which was only fairly numerous at Woods Hole according to Fish was taken in small numbers near the mouth of the bay at areas *G* and *A*. It occurred there during the months of June, July, and September, which is about the same time it was found commonly in the southern part of the North Sea, as pointed out by Ostenfeld. The specimens occurred in the surface layers where the salinities and temperatures ranged from 22.11 to 23.59 per mille, and 19.9° to 24.3° C., respectively. It is necessary to state, however, that the counts were not only small but included both dead and living specimens. *R. semispina,* a common summer form according to Bigelow and Fish during the summers of 1914 and 1922 in the region of Woods Hole, occurred sporadically during 1916 in the Chesapeake. A few specimens, only in one sample, taken at area *J* during January were found.

By far the most abundant oceanic temperate diatom found in Chesapeake Bay during the year 1916 was *Rhizosolenia alata* Brightw., possibly *f. gracillima,* although Wolfe has not mentioned this form of *R. alata* in his list. Ostenfeld has pointed out that this form is better able to stand neritic conditions and that it has been found in the lower layers of the Baltic Sea. During 1916 in Chesapeake Bay there was no indication of a maximum in April such as was characteristic for many of the neritic diatoms, nor were there any high counts in the region of the mouth of the Potomac River. It occurred in largest numbers in and near the mouth of the bay. At area *G,* during January, the counts at the surface and 18 meters were 200 (salinity 23.40 per mille, temperature 4.1° C.) and 12,700 (32.5 per mille, 5.9° C.); during March at the same depths the counts were 600 (28.15 per mille, 3.7° C.) and 2,700 (30.5 per mille, 3.4° C.); and during April the counts at those depths were almost negligible. *Rhizosolenia styliformis* Brightw., which is such an important oceanic diatom, was found in small numbers in the lower part of the bay during December, 1915, January, March, and September, 1916. The highest count was at area *F,* in the mouth of the bay, during the September cruise. Its occurrence in largest numbers during that cruise indicates that its seasonal distribution is similar to that in European waters. *Thalassiothrix frauenfeldii* Grun. was taken in very small numbers. It was found in the lower part of the bay, in the fall only.

The oceanic tropical diatoms were represented in 1916 by *Planktoniella sol* (Brightw.). Like other oceanic diatoms, it was found in very small numbers and almost invariably only in the fall and winter—that is, during the time of high salinities.

The factors governing the distribution and abundance of diatoms have been for many years and still are subjects of investigation. Currents, light intensity, temperature, salinity, and the chemical composition of the sea water have been recognized as important factors which have to be taken into consideration. All of these have received attention in a general way during the last 50 years, but within the last 5 years there has been a widespread tendency to regard the amounts of certain chemical compounds in the sea water as very important, if not the most important, factors determining distribution and abundance.

The early analysis of sea water for nitrates by Brandt (1899, 1902, 1920) and for phosphates by Raben (1905, 1910, 1914, 1920) which resulted in their emphasizing the importance of these compounds for the growth of the phytoplankton; the observations of Nathansohn (1906) stressing the importance of the sinking nutrient material in the Mediterranean; the observations of the same author (1911) at Monaco, where a diatom increase was found following wet weather; Mathews' (1918) analyses for phosphorus in the surface water of Plymouth Sound; the work of Allen and Nelson (1910) and Allen (1914) pointing out the importance of nitrates and phosphates for the growth of diatoms and the necessity of culture experiments in determining the number of diatoms in a certain quantity of water—all indicate an important relationship between the chemical compounds in the water and the distribution and abundance of diatoms.

Recently, using newer and more accurate methods for the analysis of nitrates and phosphates, Atkins (1923, 1926) and Harvey (1926) have again found a close relation between diatom increase and dissolved phosphates and nitrates in English sea waters. Gaarder and Gran's (1927) cultural work in Oslo Fjord on the growth of diatoms under variations in temperature, illumination, and nutrient salts and Gran's (1929) investigation of the sea outside of Romasdalsfjord indicate the importance of these factors.

The problem as to the factors that govern the distribution and abundance of diatoms is many sided and one in which it is difficult to study a single factor with the others under control. The efforts of Schreiber (1928) to devise such a procedure are worthy of special mention. Using single diatoms which had been rinsed by a special method so as to be free from all other organisms except supposedly a few bacteria, he determined the degree of intensity of light necessary for optimum reproduction, the quantity of nutrient materials and the temperature being kept constant. Such an approach as Schreiber has made, provided it is preceeded by a study of the organisms under natural conditions, it seems to me is very desirable.

PROTOZOA

The Protozoa occuring in the plankton samples of Chesapeake Bay were identified, counted, and tabulated by Cunningham. They are listed and their distribution is discussed from certain points of view by Cunningham in the paper by Wolfe and Cunningham (1926).

The fresh-water rhizopods were represented in the plankton by one or more species of Difflugia during the year 1916. Individuals of this form were present on all the cruises taken, and they were widely distributed. Difflugia is a bottom form, but one specie at least is known to form a gas vacuole and then to take on a tychopelagic existence (Steuer, 1910). Such a condition may account for their abundance in the plankton. Specimens of this rhizopod were taken in greatest numbers during the summer and fall cruises (July and September). The winter cruises yielded the smallest numbers.

Another rhizopod found in the bay, but on one occasion only, was the oceanic plankton form Globigerina.

Among the Silicoflagellata identified by Cunningham are two well-known species *Dictyocha fibula* Ehr. and *Distephanus speculum* Haeck., both of which have been found in the waters about Woods Hole by Fish.

During the October 1915 cruise, *Dictyocha fibula* was taken in comparatively large numbers for that species at area *A* (surface 160, 9 meters 360, 18 meters 80, 27 meters 40, 36 meters 160, 46 meters 640), and somewhat less abundantly at area *J* close to the mouth of the Potomac River. North of that area it was found in very small numbers. During the winter, spring, and summer cruises of 1916 (January, March, April, June, and July) specimens of this species were very scarce in the samples; but in September of the same year there was an indication at area *F* of increasing numbers, and the counts for the October 1915 cruise were the largest obtained on any cruise. The data, although meager, indicate that this form has an autumnal maximum in Chesapeake Bay.

The occurrence of *Dictyocha fibula* in considerable numbers at area *A* (salinity, approximately 25 to 27 per mille, temperature approximately 19° to 20° C.) and at area *J* (salinity, approximately 16 to 23 per mille, temperature approximately 18° to 19° C.) suggests that it is a neretic form as stated by Cleve (1897), although Gran has found it in mid-Atlantic ocean.

Ceratium tripos (Müller), which is such an important element in the marine plankton and which has been found in abundance by Fish at Woods Hole and by Bigelow (1926) in the Gulf of Maine, has not been reported by Cunningham (1925) for the samples taken from Chesapeake Bay. The most abundant species listed for Chesapeake Bay was *Ceratium furca* Ehr., while *C. fusus* Ehr. occurred in much smaller numbers. The data from the 1915–16 cruises of October, December, January, March, April, June, July, and September show the larger numbers during the latter half of the year and, as observed by investigators in other regions for Peridinians, after the spring maximum of the diatoms. During the cruise of July the highest counts for *C. furca* were obtained, while during the cruises of the spring and early summer the numbers were small. The surface counts for area *J*, at the mouth of the Potomac River (and many other areas), show this relation clearly: October, 208; December, 1,320; January, 320; March, none; April, 80; June, 840; July, 23,400; and September, 200.

As is the case of many diatoms the counts for the peridinian, *Ceratium furca* in the neighborhood of the Potomac River were the highest obtained in the bay. As an example, during the July, 1916 cruise, the surface counts at areas distributed along the deep-water channel from the mouth of the bay to near Baltimore were the following: *G*, 800; *A*, 4,280; *J*, 23,400; *L*, 15,320; *R*, 1,360; and *X*, 120. Of these areas, *J* and *L* are close to the mouth of the Potomac River.

While *Ceratium furca* is known as a temperate oceanic form, widely distributed over the Atlantic Ocean and occurring sparingly in the Florida current according to Cleve (1898), it has been recorded in the Baltic, where the salinity was approximately from 15 to 17 per mille by Apstein (1906), in the saline bottom water (approximately 17 to 20 per mille) entering Kieler Förde by Lohmann (1913), and in Fehmarn Belt, where the salinity was higher, by Büse (1915). Its presence in Chesapeake Bay then in comparatively large numbers near the mouth of the Potomac River is not surprising even though the surface salinity was low, approximately 16 per mille at area *J*.

Several species of the genus Peridinium were taken in Chesapeake Bay during the cruise of 1915 and 1916, but no attempt to identify them was made. Rather large numbers of individuals were found on every cruise, and they were widely distributed over the bay. The counts obtained during the June, July, and September cruises were in general the highest, while on the spring cruises, March and April, the lowest numbers were found. In other words, the data point to a summer maximum following the spring diatom maximum. A marked tendency for the highest numbers to be at or near the surface may be seen from the data, a condition which was found by Apstein (1906) in the North Sea. (See Steuer, 1910.)

The data do not show that the highest counts were found usually in the neighborhood of the mouth of the Potomac River, although such was the case especially during the July and September cruises.

Many specimens belonging to the genus Prorocentrum (two forms of *P. micans* according to Cunningham) were collected during the 1915 and 1916 cruises. By far the largest numbers were found at the time of the summer and fall cruises, and the smallest during the midwinter and spring cruises. At area *J* the surface counts were these: October (year 1915), 1,560; December, 320; January (year 1916), 360; March 40; April, 200; June, 480; July, 8,440; September, 4,200. At 27 meters the counts at the same area were: October, 448; December, 120; January, 120; March, no count; April, 280; June, 120; July, no count; September, 4,480. The numbers found in the surface samples during the cruises of July and September were highest in the region of the mouth of the Potomac River, but during other months this relation did not hold. In fact the two largest counts taken in the bay were 15,320 at area *R* in October and 92,800 at area *X* in June—both surface samples collected far northward in the bay. The time of occurrence of the maximum counts for this genus and for other Dinoflagellata mentioned above supports Kofoid's suggestion (1921) that the increase in numbers may be related to the decay of phytoplankton, but it is also true that the increase in number took place when the temperature was highest and the light strongest.

Noctiluca miliaris Surivay, a protozoan belonging to the group Cystoflagellata was found on nearly every cruise in 1915 and 1916. This form, according to Ostenfeld's résumé (1913), occurs only in coastal waters, not in the open ocean and not in water of too low salinity like that of the Baltic Sea. Bigelow (1926) has not taken it in the Gulf of Maine, and Fish (1925) did not report it from Woods Hole. Its decidedly irregular distribution in Chesapeake Bay bears out the statement of Ostenfeld that individuals may appear in large numbers in a certain place, stay for several weeks, and disappear then, while a short distance away they never become numerous. A few specimens of Noctiluca made their way north as far as area *X* in Chesapeake Bay during 1915 and 1916, but it was only in the lower end of the bay that they occurred in considerable numbers. The data show the highest numbers at the surface and the largest count (2,400) was that in a surface sample taken at area *F* during September, 1916. While the distribution in the bay was quite irregular, the data point to a maximum in the fall with considerable numbers in the spring and early summer. During the cruises of January and March almost no specimens were recorded, while during the cruise of July the numbers were low. No conclusion can be reached as to the distribution with reference to the mouth of the Potomac River except that the outstanding high counts were not there but in the region of the mouth of the bay.

A rather large number of genera belonging to the Infusoria were represented in the plankton samples, and they have been listed and the numbers tabulated by Cunningham in the paper of Wolfe and Cunningham (1926). Of these only one genus, Cyttarocylis, belonging to the Tintinnidae has been studied sufficiently to make it possible to draw any conclusions as to distribution. Specimens were found on every cruise during the year 1916 (January, March, April, June, July, and September). The highest counts were obtained from samples taken during the March cruise, and the numbers were more abundant in the samples from the lower part of the bay.

COELENTERATA

PORIFERA

Practically all of the collecting done on the survey was in the offshore waters, so that the sponges of the shallower water have not been investigated. Dredging with the beam trawl and with the mud bag at the shallow stations have brought to light, however, four species of sponges, one of which is new, and a new variety. These have been identified by H. V. Wilson, and I am indebted to him for the following list: *Tetilla laminaris* George and Wilson, *T. laminaris* var. symmetrica n. var., *Suberites paradoxus* Wilson, *Halichondria panicea* Johnston, and *Microciona prolifera* Verrill.

Tetilla laminaris was dredged on one occasion only at 10 meters at area *K*. This area is located on the eastern side of the bay opposite the mouth of the Potomac River. The specimen was taken during July, 1920, in water of 14.79 per mille salinity and 24.4° C. temperature. The bottom in this region was partly sandy and partly muddy (depth 10 meters). *T. laminaris* George and Wilson, var. symmetrica was found growing at area *D*, off New Point Comfort (depth of 8 meters) on a sandy bottom. Three specimens were brought up during the April, 1920, cruise from water of 21.23 per mille salinity and 11.1° C. temperature. A new species, *Suberites paradoxus* was dredged during the July, 1920, cruise at area *C*, off New Point Comfort (depth about 13 meters). The bottom in this region was variable in character, and the temperature and salinity of the water from which the specimen was taken were 22.0° C. and 22.49 per mille. During the January, 1921, cruise numerous fragments of *Halichondria panicea* were found at area *Q* (depth about 14 meters) off Sandy Point and at area *A* (depth about 46 meters) near Cape Charles City. In the first case they were taken from water of 21.59 per mille salinity and 4.2° C. temperature, while in the second case the salinity and temperature were about 26.00 per mille and 4.9° C. *Microciona prolifera* was dredged during the July, 1920, cruise at area *P* (depth about 13 meters) off Point No Point and area *I* (depth about 13 meters) just south of the Maryland and Virginia line. The salinities were 17.27 per mille and 15.47 per mille, the temperatures 23.5° C. and 25.2° C., respectively.

Undoubtedly the ideal home for sponges is in a region where there are plenty of solid objects for attachment, so one finds them living well among rocks, stones, shells, corals, etc. They are known not to do so well in regions where the bottom is made of soft mud or fine sand. For example, in the deeper part of the fjords (Appellöf, 1912) of Norway, where the bottom is muddy, the sponges are absent. It is not surprising, then, that many specimens or species of sponges were not found during the offshore dredging in Chesapeake Bay, since much of the bottom in the deeper parts of the bay is muddy. It is of interest to note that all of the specimens collected, with the exception of one, were taken from regions where the depth ranged from 8 to about 14 meters—in other words from the shallower areas of the bay. No sponges were dredged from the mouth of the bay, which is largely a region of shifting sand. All the specimens found come from the lower half of the bay, below area *P*, near the mouth of the Potomac River, and none were taken in water of a lower salinity than 14.79 per mille.

CNIDARIA

HYDROZOA

The hydroids collected in the deep waters of Chesapeake Bay have been studied by Charles W. Hargitt. He has identified 14 species and listed those identified and described for Chesapeake Bay by C. C. Nutting (1901) and S. F. Clarke (1882). By far the most abundant hydroids collected by our survey belong to the genus Thuiaria. Three species, one of which at least is of commercial importance, have been reported from the bay and its tributaries by Nutting. They are *Thuiaria argentea* Linn., *T. cupressina* Linn., and *T. plumulifera* Allman. Hargitt in working over the collections of the year 1920 found *T. argentea* at many stations and speaks of it as "by all odds the most common species taken." The beam trawl hauls show that Thuiaria was found widely distributed over the deeper parts of the bay; but the indications are, as has been pointed out by Radcliffe in the log for the 1916 cruises and by Hargitt, that some of the material taken was unattached to the substratum, although not floating at the surface. Ordinarily roots were not found on the specimens. Floating hydroids have been observed by Bigelow (1915) on Georges Bank off Cape Cod and their occurrence is discussed by C. McLean Fraser in Bigelow's paper (1915). R. C. Osburn, who has studied the Bryozoa collected in the Chesapeake by this survey, has commented on the large amount of dead hydroid material received by him with Bryozoa attached, and suggests that they were brought into the bay by tides and currents from near the mouth, where they grow. The observations of Radcliffe (1916) showed that Thuiaria had increased in abundance during the March and April cruises as compared with the supply during the previous winter. The indications are that the Thuiaria species can withstand a large range of salinities and of temperatures.

The following hydroids are known to occur in the region of Fort Wool, Va.: *Calyptospadix cerulea* Clarke, *Eudendrium carneum* Clarke, *Stylactis arge* Clarke, *Lovenella gracilis* Clarke, *Bougainvillia rugosa* Clarke, and *Hydractinia echinata* Fleming. Several other hydroids have been collected from Chesapeake Bay, and they are now in the United States National Museum. The following list is available owing to the courtesy of Waldo S. Schmitt, curator of invertebrates: *Campanularia* sp., *Thuiaria argentea* (L) from Jerome Creek, Md., *T. cupressina* (L) off Virginia, *T. plumulifera* Allman, *Aglaophenia rigida* Allman, *Cladocarpus flexilis* Verrill off Virginia, *Antennularia americana* Nutting, *A. antennena* (L), *A. simplex* Allman, *Plumularia floridana* Nutting, and *Plumularia*, near *alternata*. Two of these species, *A. antennena* and *P.* "near *alternata*," were determined by Verrill and the rest by Nutting.

HYDROMEDUSÆ

The hydromedusæ collected during the July, August, October, and December cruises of 1920 and the January and March cruises of 1921 have been examined and identified by H. B. Bigelow. I am indebted to him for the information that the collection contains no new species and that no extensions of any importance to the geographic ranges were found. He points out that there are very few species, and that the well-known form *Nemopsis bachei* greatly predominates in the collection. This form, which occurs very abundantly along the Atlantic coast near the mouths of large bays into which pure ocean water has free access (Mayer, 1910), was found widely distributed in Chesapeake Bay during the cruise of December, 1920. It was taken frequently in the surface nets as well as in the bottom net, and the records show its occurrence as far north in the bay as area W, off Bloody Point. The records also show that this form was present in the bay during the cruises of July, August, October, 1920, and January and March, 1921. A few other hydromedusæ were collected, some of which were identified provisionally. The complete list is as follows: *Bougainvillia carolinensis* McCrady, *B. ramosa* Van Beneden (provisional identification), *Nemopsis bachei* L. Agassiz, *Blackfordia virginiana* Mayer, *Liriope scutigera* McCrady (provisional identification), and *Aglantha digitale* Fabricius (too fragmentary to throw light on varietal relationships).

SCYPHOMEDUSÆ

By far the most common jellyfish (or sea nettle, as it is called), in the region of Chesapeake Bay is *Dactylometra quinquecirrha* L. Agassiz. It occurs there usually in the "Chrysaora" stage, characteristic of the brackish water—that is, with 32 marginal lappets and 24 tentacles and mature gonads instead of with 48 marginal lappets and 40 tentacles (R. P. Bigelow, 1890; Mayer, 1910). Mayer reports (p. 588) that *D. quinquecirrha* in the 40-tentacle condition develops at the mouth of Chesapeake Bay "in the purer ocean water * * *" The unpublished observations of Radcliffe on cruises during October and December, 1915; January, March, April, June, July, August, and September, 1916, give a good idea of the seasonal abundance of older specimens of Dactylometra in the bay. During the October cruise this form was reported at practically every station from the mouth to Sandy Point, near Baltimore; on the December cruise it was seen very infrequently; during the cruises of January, March, April, and June it was not reported, although, of course, it may not have been entirely absent; on the July cruise it was very abundant, especially at the mouth of the bay and was found as far north as area *X*; finally, during the September cruise it was still abundant at many stations. The records indicate that Dactylometra became abundant in the Chesapeake during July, 1916, and according to Radcliffe one fisherman, at least, in the southern part of the bay, anticipates a "run" during that time of the year and takes up his nets to prevent their "burning." Midsummer and early fall apparently was the time of abundance of this form in Chesapeake Bay during 1916, a conclusion which agrees with observations made along the New England Coast and at Tampa, Fla. Dactylometra in the "Chrysaora" stage has been found in considerable numbers by the writer in the Severn and Magothy Rivers during October, and Mayer reports it from St. Marys River, Md., early in November, 1904 and 1905. E. A. Andrews has found it in the fall, 10 miles up the Severn River and about the docks in Baltimore Harbor. Undoubtedly it is the common form during the fall in the rivers emptying into Chesapeake Bay. *Dactylometra quinquecirrha*, according to the observations of H. B. Bigelow for the New England region, is strictly a coastal form and does not occur north of the Cape Cod region. In its "Chrysaora" stage it is able to survive through a large range of salinities, judging from observations made in the Chesapeake; but its geographical distribution indicates that it is a warm-water form.

It is not improbable that Dactylometra breeds in Chesapeake Bay and that the planulæ, scyphostomæ, and ephyræ are present in the summer, winter, and spring, respectively, but the records on which the above discussion is based deal only with the older and easily seen specimens. However, the ephyræ of *Dactylometra quinquecirrha* have been seen by W. K. Brooks at Fort Wool, in the southern part of the bay, and figures made from them have been published by Mayer (1910).

The common jellyfish of the Atlantic coast, Aurelia, was not found in large numbers during 1916, but during the March cruise it was taken in considerable numbers in the southern half of the bay. The reddish-colored jellyfish Cyanea, which, according to Damas (1909) and also Bigelow, is characteristic of coast or bank water, appears in Chesapeake Bay at times. It was abundant during the April cruise of 1916 and was found at almost every station from area *J*, at the mouth of the Potomac River, to area *X*, near Baltimore. During the August cruise of 1920 a few large specimens were seen in the region of the Potomac. E. A. Andrews reports having seen small specimens in the waters of the eastern side of the bay near Love Point, which is only a few miles from Baltimore.

ANTHOZOA

Slender branches of a gorgonian have been collected on many cruises during 1916, 1920, 1921, and 1922. These whiplike branches, which may be as much as 60 or 70 centimeters long, measure scarcely over 1 millimeter in diameter. Some are yellow and others reddish in color. They have been taken in the beam trawl and the bottom townet at stations near the mouth of the bay ordinarily, but not infrequently specimens have been found in the region of the mouth of the Potomac River. During June, 1921, a few fragments were collected as far north as area *R*, off Barren Island near the mouth of the Patuxent River. None of the specimens was attached to stones, shells or other objects, and so there was no evidence to show that they were growing on bottom materials. During the May-June cruise of 1921 specimens were brought up from the following areas: *G′* off Old Point Comfort; *H* at the mouth of the Rappahannock River; *I* near the mouth of the Potomac River; *N* in the mouth of the same river; *L′* off Holland Island; and *R* off Barren Island. On no other cruise was such an extensive distribution noted—that is, over more than the lower half of the bay—but in March, 1922, it was found as far north as the mouth of the Potomac River. The records indicate that this gorgonian may be found in the bay at any season, in shallow or deep water, but that it does not reach the upper parts of the bay. An attempt to identify this species from descriptions made by Verrill lead me to believe that it is identical with or closely related to *Leptogorgia virgulata* (Lmk.), but the fragmentary character of the specimens and the lack of confirmation of such an identification by specialists make it necessary to consider the conclusions as tentative. A. Knyvett Totten, who is working on the gorgonians of the British Museum, has examined specimens of the species found in the Cheaspeake, and although he has not had access to Verrill's material is of the opinion that our species is *L. virgulata*.

Only one species of sea anemone has been collected in Chesapeake Bay during the cruises of 1916, 1920, 1921, and 1922, but these cruises were limited to operations in offshore waters. This unidentified species had a surprising distribution, judging from our dredging collections, being found at area *Z* on the following cruises: 1920, August, October, and December; 1921, June; 1922, March; area *W*, 1920, December; 1921, June; area *V*, 1921, June; area *T*, 1920, July; area *R′*, 1921, March; area *P*, 1921, June; and area *I*, 1920, July. In other words, it was not found below the mouth of the Potomac River, and it was taken most often at area *Z*, off Sandy Point, not far from Baltimore. It was always brought up attached to rocks, shells, slag, or other hard objects. This form was never taken in the deep-water channel, possibly because of a lack of shells and stones for attachment. It was found only in water from 7 to 12 meters deep, but probably it may be found, by shore collecting, in shallower water; in fact,

E. A. Andrews reports the occurrence of an anemone (probably of the same species) from the Severn several miles above Annapolis. It seems to be adapted to water of a rather low salinity but to an extensive range of temperatures. However, it must not be forgotten that another factor affecting the distribution is the presence of hard objects for attachment. The 12 samples mentioned above were taken in water which varied in salinity from 11.46 to 18.47 per mille, and in temperature from 5.3 to 24.1° C.

Fragments of a coral which were probably the calcereous portions of *Astrangia danæ* Agassiz were brought up on 9 different occasions by the beam trawl or the mud bag. These were all found near the mouth of the bay—4 times at area *G*; 5 times at area *E*; once near Cape Henry (all three of which localities are directly in the mouth of the bay); and once at area *A* off Cape Charles City. In addition to this, Radcliffe reports finding "white corals, many growing on stones" at station 8592 near Cape Henry in about 18 meters of water.

CTENOPHORA

The ctenophores are a conspicuous element in the plankton of Chesapeake Bay at certain times of the year. They were so abundant during some of the cruises of 1920, 1921, and 1922 that they interferred with the proper working of the townets. No attempt was made to study the ctenophores intensively, and whatever records we have are the result of general observations on their relative abundance made when the nets were brought in. *Beroë ovata* Chamisso and Eysenhardt is known to occur in the bay. It was collected by Mayer (1912) from St. Marys River, Md., in November, 1905, and has been figured in his monograph on the ctenophores. *Beroë forskalli* was reported by Bigelow (1922) as being present in the mouth of the bay and outside in July, 1913. Radcliffe, in the unpublished log, reports the presence of a "Pleurobrachialike" ctenophore at stations near the mouth of the bay—for example, at areas *G* and *A* in March, 1916, and again at areas in the same general region in April, 1916. Very probably the species was *Pleurobrachia pileus* or possibly the nearly related species *P. brunnea*, if the latter is a valid species. It is also probable that *Mnemiopsis gardeni*, which is known to frequent brackish-water bays and estuaries from Chesapeake Bay to northern Florida, was common in the bay. During the January cruise, 1916, ctenophores were abundant in several localities, but on the March and April cruises they were scarce except at stations near the mouth of the bay. They were abundant in the southern half of the bay during the June cruise and all over the bay on the July cruise, although in greater numbers in the upper half. The ctenophores were still very abundant in the upper waters of the bay and extremely abundant near the mouth of the Potomac River during the September cruise. Similar conditions were found in 1920. During the January, 1920, cruise they were numerous all over the bay, but in March they were found only at areas *E*, *F*, and *G*, which are in the mouth of the bay. On the May cruise they were still scarce; but on the July, October, and December cruises they were again numerous all over the bay, and especially so near the mouth of the Potomac in December.

The ctenophores were still widely distributed over the bay during the January cruise of 1921, but again as in 1916 and 1920 the hauls so far as made on the March cruise showed a scarcity. It must be stated, however, that at many areas during this cruise the nets were not used. On the May-June cruise the ctenophores were more numerous. Finally, again during the January and March cruises of 1922, they showed conditions similar to other years—that is, a wide distribution during the

January cruise and a great scarcity in March. While the discussion just given is not based on a careful quantitative study of the abundance of the ctenophores, the fact that there is close agreement between the observations made by Radcliffe in 1916 and by the author in 1920, 1921, and 1922 as to relative abundance makes the conclusions of considerable value. The evidence all supports the view that a scarcity of full-grown specimens, at least, occurs during the spring months (for example, March, 1916, 1920, 1921, and 1922), that the numbers increase in early summer, that they reach a maximum in the late summer and fall, and that during part of the winter they are still present, widely distributed. In the late fall and early winter the writer has found them several miles up the Severn River.

Our observations on the seasonal occurrence of ctenophores in Chesapeake Bay are in rather close agreement with those made by Nelson (1925) for the inland coastal waters of New Jersey.

VERMES

NEMATHELMINTHES

NEMATODA

The collection of nematodes, which is large, is now in the hands of Dr. N. A. Cobb, senior nematologist of the Department of Agriculture. He has been working on them for some time and finds that the five hundred and odd specimens comprise at least a dozen genera (Oncholaimus, Chromodora, Euchromodora, Enoplus, Anticoma, Spilophora, Monhystera, etc.). The number of species he states are "upward of 20, some of them doubtless new." No further discussion of this group can be made at the present time.

CHAETOGNATHA

The occurrence of sagittas, ordinarily thought of as marine planktonic forms, in the waters of Chesapeake Bay is not surprising when it is known that one species at least has been found in the Baltic Sea (Apstein, 1911, p. 174; Ritter-Záhony, 1911, p. 19) and since the investigations of Huntsman and Reid (1921, pp. 10–14) have shown that *Sagitta elegans* was found in brackish water estuaries where the salinity was probably as low as 20 per mille. Three species *Sagitta elegans* Verrill, *Sagitta serratodentata* Krohn, and *Sagitta enflata* Grassi represent the sagittas collected during the cruises of July, August, October, December (1920), and January, March–April (1921). The writer made the identifications following the classifications of Ritter-Záhony (1911) and Huntsman (1919), although no attempt was made to distinguish subspecies. Of the three species mentioned, specimens of *Sagitta elegans* were by far the most abundant, and specimens of *S. serrotodentata* barely made their appearance inside of the bay.

The studies of Huntsman (1919), Bigelow (1922, 1926), and myself all lead to the conclusion that *Sagitta elegans* is primarily a neritic form. This species, however, was all but absent from Chesapeake Bay during the July and August cruises, judging from numerous surface (over 100), and bottom towings (over 40), and vertical hauls (30) made at widely distributed areas. Only at areas *G* in the mouth and *B* near by were any specimens captured. All of these were small forms varying from about 4 millimeters to 10 millimeters in length, and only one specimen was taken in the surface nets. Additional evidence indicating a scarcity during the summer is afforded by the records in the log for the May–June cruise of 1921, which show that no sagittas were seen in any of the unpreserved samples as they came to the surface. Such a condition suggests that the sagittas are really immigrants into the bay. It is of much interest to find that the towings of the October cruise revealed considerably larger numbers of *S. elegans* in Chesapeake Bay than those of the summer cruises, and also to recall that this cruise took place during the time of year when there was a strong tendency for the deeper and more saline layers to move into the bay. The records, which deal with the usual large number of surface and bottom towings, show that all the specimens were small, about 4 to 10 millimeters in length, and that they were distributed as far north in the bay as area *X*. While there were many surface towings made, all of the specimens came from the bottom net (which, however, was not a closing net), indicating that *S. elegans* was confined largely to the deeper and more saline waters in the daytime, at least when all the samples were taken. By far the largest catches were in the mouth of the bay, and the numbers showed a fairly uniform decreasing range for the successive areas passing toward the head. The following data for the bottom net (10 minutes towing) illustrate this: Area *G*, 927 specimens, largest 6 to 7 millimeters long; area *F*, 805 specimens of about the same size as those for area *G*; area *A*, 5 specimens 4 to 7 millimeters long; area *B*, 33 specimens mostly about 8 to 10 millimeters long; area *C*, 16 specimens about 8 to 10 millimeters long; area *Q*, 42 specimens ranging up to 10 millimeters long; area *H′*, 5 specimens 4 to 7 millimeters long; area *I*, 3 specimens about 6 to10 millimeters long; and area *X*, 1 specimen about 9 millimeters long. No large specimens were found.

While it is probable that *Sagitta elegans* breeds to some extent in the bay, the absence of large specimens during the October cruise, the large number of young specimens in the waters of the mouth of the bay with a decreasing number farther in, the autumnal hydrographic conditions, and at the time of the July and August cruises an almost complete absence of it from the hauls, indicate that the bulk of the specimens found during the October cruise were being transported gradually from their breeding place, probably just outside of the capes, into Chesapeake Bay.

The towings of the December cruise showed no large numbers of *Sagitta elegans*, nor was the distribution over the bay extensive. In fact, practically all of the specimens were taken in the mouth of the bay and close by. Only small individuals, from 3 to 11 millimeters in length, were captured, although the usual number of towings was made.

During the January (1921) cruise, the usual, numerous towings all over the bay brought in rather large numbers in the lower half of the bay—that is, from area *J* to the mouth—but north of area *J* no specimens were captured, although many surface and bottom towings were made. At this time specimens of *Sagitta elegans* of rather large size, as much as 25 millimeters long, were taken, but in addition there were many smaller individuals which graded down to 4 millimeters in length. A good idea of the character of the catches may be had from the following data for the bottom net (10-minute towings): Area *F*, 106 specimens (seven 20 to 25 millimeters long, 79 larger than any captured in earlier cruises but none 20 to 25 millimeters long, and the rest of the 106 graded from 6 to 10 millimeters long); area *E*, 17 specimens (six 15 to 21 millimeters long and eleven 4 to 10 millimeters long); area *B*, 60 specimens grading from 5 to 24 millimeters long; area *C*, 1 specimen 17 millimeters long; area *Q*, 1 specimen 25 millimeters long; area *H*, 4 specimens, the largest 17 millimeters long; and area *J*, 3 specimens 20 to 22 millimeters long. Only four of the large number of surface towings yielded any specimens. These, only 10 specimens in all, were mostly small.

The towings from the March–April cruise possibly show the culminating effect of the inflowing bottom current characteristic of the fall and winter months, by the very large catches of *Sagitta elegans;* although the large numbers of small specimens, some of them only 1 or 2 millimeters long, in addition to many large specimens, even in the upper part of the bay indicate that the great abundance was due in part to breeding taking place in the bay. A large number of the specimens collected during the March–April cruise were in good condition but some of the larger specimens were shrunken. Whether this condition indicated the passing of the breeding season for those individuals, or whether it was the result of the effect of low salinity, I am not prepared to say. The following data for the bottom net (10-minute towings) which must be considered as covering only the upper half of the bay since no surface or bottom towings were made south of the mouth of the Potomac River or more precisely south of areas *R′* and *R* off Barren Island, show that the catches (given in round numbers) were much larger in that region than those of any other cruise: Area *R′*, 70 specimens, the largest of medium size and grading down to 2 millimeters in length; area *R*, 2 specimens; area *T*, 120 specimens of medium size; area *S*, 1,850 specimens (nine 26 to 28 millimeters long, 1,841 grading down to 1 to 2 millimeters in length); area *V*, 26 specimens in poor condition (salinity not over 9.16 per mille, shallow area, 9 meters in depth); area *Z*, 7 specimens, one 22 millimeters long; area *Y*, 1,650 specimens, the largest 31 millimeters long and grading down to 2 millimeters in length. This surprisingly large catch at area *Y*, which is off Love Point, not far from Baltimore, was made in water the salinity of which was not higher than 12.99 per mille. On the same day about two hours earlier one of the two largest catches of Copepods for all the cruises was made at area *Z* close by.

The catches of *Sagitta elegans* taken in Chesapeake Bay are of interest because of the large numbers of small specimens and the small numbers of large specimens, the latter being limited to the January and March–April cruises. The capture of only one specimen reaching 31 millimeters in length indicates that this species does not grow as large in the Chesapeake Bay region as farther north, where it is colder, and supports the conclusions of Huntsman (1919, p. 447) and Bigelow (1926, p. 320) that the size of *S. elegans* is dependent upon the temperature. Another point of interest is the occurrence of some very small specimens of *S. elegans*, at least during all of the cruises (July, August, October, December, 1920, and January, March–April, 1921), even though limited to the mouth of the bay. Such a condition indicates that *S. elegans* breeds continuously during those months, outside or inside of the bay, and leads to the suspicion that it may breed to some extent throughout the summer off Chesapeake Bay, as Bigelow (1926, p. 314) has found to be the case on the Georges Bank.

Owing to the fact that the so-called "bottom net" used on our cruises was not of the closing variety, no definite information can be had as to the vertical distribution or as to the precise salinity in which specimens brought up in that net lived. The scarcity of specimens in the surface nets during all cruises shows clearly, however, that *Sagitta elegans* was almost confined to lower layers during the daytime, at least. All of the towings in the bay were made in the daytime. The studies of Huntsman and Reid (1921, p. 12) in the estuary known as the Magagnadavic River show that there was a tendency for *S. elegans* to remain near the bottom, at least during the bright half of the day. As might be expected, we found *S. elegans* in water of 29 to 30 per mille salinity outside of the capes, but large numbers of small specimens grading up to specimens over 30 millimeters long were found in good condition at area *Y* in water of not more than 13 per mille salinity. (Surface salinity at this area, 5.26 per mille; bottom salinity, 18 meters, 12.99 per mille.) This haul was made in March, 1921; and undoubtedly it was not an unusual condition for that time of the year, because the log in which were recorded the conspicuous organisms in the hauls at the time they were brought to the surface shows that in March, 1920, and March, 1922, sagittas were present in the same region, close to area *Y* (surface) and at area *X*, respectively. The salinity of the water in which the specimens were found at the former area was 11.63 per mille and at the latter area not more than 16.79 per mille. The great abundance of *S. elegans* in Chesapeake Bay even at the time of low salinities and the small numbers of *S. serrotodentata*, *S. enflata* and other sagittas, in so far as our records show, indicate that *S. elegans* is adapted to a large range of salinities, while the other species are not. However, it does not follow that the degree of salinity of the water is the only factor which accounts for the horizontal distribution found in Chesapeake Bay. The specimens caught at the surface were too meager in number to make any comparison of the relative numbers at the mouths of rivers as compared with other regions or to study differences on the east and west sides of the bay which might possibly be due to differences in salinity.

It is generally believed that the temperature of the water is another factor governing the horizontal distribution of *Sagitta elegans*. The scarcity of specimens in the bay during the summer cruises, when the comparatively shallow waters are heated to as much as 24° C. at the bottom and 27° C. at the surface, and their abundance during the coldest season, when the temperature drops to near 0.0° C. at the surface and a degree or so higher at the bottom, suggests the importance of temperature in determing the distribution. But other factors, such as an abundance of food, must be be considered; and in this connection it is of special interest to note that during the March–April cruise (1921), when *S. elegans* was so abundant in the upper bay, at least, C. B. Wilson found the copepod *Acartia clausii* in maximum numbers in the same region. It is known that copepods are an important food of sagittas, and Bigelow (1926, p. 320) has pointed out the probable dependence of the distribution of *S. elegans* on the calanoid copepod plankton. In the case of vertical distribution the intensity of light should not be neglected. Finally, dominating fall and winter in-going bottom currents must be considered as probable factors affecting the seasonal and horizontal distribution of *S. elegans* in Chesapeake Bay.

Our records show that *Sagitta enflata* was scarce in Chesapeake Bay during all the cruises. It was taken almost as seldom as *S. serratodentata*. *S. enflata* is recognized as a tropical form, characteristic of the surface waters of the Gulf Stream (Huntsman, 1919, pp. 425, 426; Ritter-Záhony 1911, p. 17; Bigelow 1917, p. 298; Bigelow 1926, p. 334). Huntsman has found it as far north as 43° 30′ N, off Nova Scotia; while Bigelow has taken it off Marthas Vineyard, off the coast of New Jersey, and as far south as the region of Chesapeake Bay. Fish (1925) does not report it from Woods Hole. No specimens were captured in the Chesapeake Bay during our July and August cruises (1920), although a few were found outside; but on the October cruise 4 specimens were taken at area *Q*, 2 at area *A*, and 10 at area *B*. The two latter areas are near the mouth of the bay while the former one is a little farther north abreast of the mouth of the Rappahannock River. It was somewhat surprising to find specimens of *S. enflata* at area *Q*, but the sausage-shaped ovaries with large eggs and short tail convinced me of the identity of the specimens. Furthermore, they were compared with some of Conant's preparations and were in perfect agreement. During the December cruise five specimens were found in the mouth of the bay at areas *G*, *F*, and *E;* while on the January (1921) cruise only one specimen, badly distorted, was caught. It was taken in the mouth of the bay at area *C*. No specimens were obtained during the March (1921) cruise. The scarcity of this sagitta in the bay and its practical absence after the December cruise indicate that it is an oceanic tropical form.

The only other sagitta which has been captured by our nets in Chesapeake Bay is *Sagitta serratodentata*, another tropical form which is characteristic of the Gulf Stream (Bigelow 1926, p. 58) but which may spread shoreward during warm summers. Bigelow (1915, pp. 299 and 300) found it well in toward the mouth of Chesapeake Bay in July, 1913, and Huntsman (1919, p. 442) speaks of it as being a cosmopolitan and epiplanktonic, warm-water form whose distribution in the Gulf of St. Lawrence region extends farther inshore than any other sagitta, being able to withstand the lower temperature and salinity better. While *S. serratodentata* was found outside of Chesapeake Bay in considerable numbers during our August cruise, only five specimens were discovered inside the bay. One was taken at area *G* in August, 1920, another at area *F* in January, 1921, and three specimens at area *E* during the same cruise. All of these areas are in the mouth of the bay. During the July, October, December, and March–April cruises no specimens were found. The specimens captured were all small, varying from 9 millimeters to 15 millimeters in length.

During the August cruise, surface towings were made outside of the bay at three stations (8832, 8833, 8835) where the depths were 118 fathoms (214.5 meters), 67 fathoms (121.8 meters), and 20 fathoms (36.4 meters), respectively. A few specimens of *Sagitta elegans* (35, 1, and 32 after 30 minutes towing), all not more than 10 millimeters in length, were taken in each haul. These three towings were made during the following periods of time: 5.13 p. m. to 6.16 p. m., 7 p. m. to 7.55 p. m., and 11.05 p. m. to 11.45 p. m., respectively, and throughout the work the sky was partly cloudy and the atmosphere hazy. Four specimens of *S. enflata*, three of them over 25 millimeters long, were taken in these surface towings, all four at station 8832, but no specimens of *S. serratodentata*. Towings with a nonclosing bottom net for 30 minutes at each of the three stations—8832, 8834 (43 fathoms or 78.2 meters depth), and 8835—yielded 43 specimens of *S. elegans* of various sizes up to 14.5 millimeters in length at station 8834; 15 specimens, some as large as 12 millimeters in length, at station 8835; and no specimens at station 8832. On the other hand, the same bottom towing sample at station 8832, which it will be remembered was the farthest out in the Atlantic Ocean (depth 118 fathoms or 214.5 meters), and which I have just said yielded no *S. elegans*, brought up 133 specimens of *S. serratodentata*. The bottom towing sample at station 8834 nearer the mouth of the bay (43 fathoms or 78.2 meters depth) which brought up 43 specimens of *S. elegans*, captured 40 specimens of *S. serratodentata*. The individuals of the latter species were all small, varying from about 7 to 17 millimeters in length. Finally, the bottom towing sample at station 8835, close to the mouth of Chesapeake Bay (depth 20 fathoms or 36.4 meters) with its 15 specimens of *S. elegans* brought to light only 2 specimens, both about 12 millimeters long, of *S. serratodentata*. Specimens of *S. enflata* were extremely rare in all of the bottom towings just mentioned. Two, one of which was 21 millimeters long, were taken at station 8832 and one at station 8834. While the use of a nonclosing bottom net and the limited number of samples makes it impossible to draw any conclusions of unquestionable trustworthiness concerning the precise vertical distribution of *S. elegans* and *S. serratodentata*, the indications are that during the August cruise the latter species was more abundant in the deeper layers, since practically no specimens (only 3 specimens at station 8834 and 1 at station 8837) were found in the surface hauls. The gradually decreasing numbers of specimens of *S. serratodentata* from the 100-fathom line to the mouth of Chesapeake Bay, as seen in surface and bottom towings, and the practical absence of this species in the bay throughout our cruises are in keeping with Bigelow's (1922, p. 153) statement that it is the "more oceanic" of the two species under consideration.

BRYOZOA

The offshore waters of Chesapeake Bay have yielded 17 species of Bryozoa. These have been identified by R. C. Osburn. He calls attention to the fact that the number is small for such a large area, but it should be mentioned that the survey covered only the deeper waters and that no special efforts were made to investigate one region more than another in order to find a larger number of species of this group.

The list of species follows: *Barentsis discreta* (Busk), *Crisia eburnea* (Linnaeus), *Bugula gracilis* var. *uncinata* Hincks, *Bugula turrita* (Desor), *Electra pilosa* (Linnaeus), *Membranipora membranacea* (Linnaeus), *Hemiseptella denticulata* (Busk), *Hippothoa hyalina* (Linnaeus), *Schizopodrella unicornis* (Johnston), *Microporella ciliata* (Pallas), *Alcyonidium verrilli* Osburn, *Alcyonidium parasiticum* (Fleming), *Anguinella palmata* Van Beneden, *Bowerbankia gracilis* var. *caudata* (Hincks), *?Amathia alternata* Lamouroux, *?Victorella pavida* Saville Kent, and *Triticella elongata* (Osburn).

Most of the specimens collected were taken from the shallower areas of the offshore waters. Only a few specimens came from the deep holes such as areas *A*, *J*, *R*, and *S*. *Amathia alternata* which Osburn found in abundance on the beach at Beaufort, N. C., was dredged from area *G* in the mouth of the bay; area *G′*, nearby, off Old Point Comfort; and areas *A*, *B*, and *C*, which mark a line across the bay from Cape Charles City to New Point Comfort. Its distribution in Chesapeake Bay seems to be limited to the extreme lower end of the bay, as has been pointed out by Osburn, and it was found only in water of a bottom salinity ranging from about 22 to 31 per mille.

Eight other species, *Barentsia discreta* at area *A* (23.96 per mille), *Bugula gracilis* var. *uncinata* at area *A* (27.06 per mille), *Electra pilosa* at area *F* (31.08 per mille), *Hippothoa hyalina* at area *E*, *Schizopodrella unicornis* at area *B* (24.33 per mille), *Microporella ciliata* at area *E*, *Alcyonidium parasiticum* at area *F* (31.08 per mille), and *Bugula turrita* at area *E* were taken only once and at the areas mentioned. While all of these localities are at the extreme lower end of the bay, the number of specimens collected is so small that little should be said of the distribution.

One of the most abundant bryozoans found in the bay was the large, fleshy *Alcyonidium verrilli*, which has been recorded before only from southern New England and New Jersey. Osburn has stated that it was found at areas all over the southern half of the Chesapeake Bay but no farther north than at area *L*, which is close to the mouth of the Potomac River. Its frequent capture in the region mentioned during all cruises and the entire lack of specimens from area *L* to area *U*, near Baltimore, during the same cruises constitute convincing evidence that its distribution was limited as just described. It occurred in water of a salinity ranging from about 13.00 to 26.00, or more.

Two species, *Bowerbankia gracilis* var. *caudata* and *?Victorella pavida*, have a greater range from north to south, according to the data at hand, than any other species collected. The former was found at areas *B*, *I*, *L*, *P*, and *S* in water of salinities ranging from 23.87 to 15.71 per mille, while the latter, which, as Osburn has pointed out, is supposed to frequent waters of only slight salinity, was dredged at areas *A*, *C*, *K*, and *S*, which range from Cape Charles City to the region of James Island. The salinities ran from 27.06 to 17.44 per mille.

The distribution of *Anguinella palmata* is of interest since it was found only well within the bay—a distribution which appears to be characteristic of the species, according to Osburn. It was collected almost exclusively from the region close to the mouth of the Potomac River. During the cruises of July, August, and December, 1920, and January and March, 1921, it was dredged at area *I;* in December at areas *J* and *L;* in January at area *N*, and in December at area *H*. Areas *I*, *J*, and *L* lie close to the mouth of the Potomac, *N* just inside the mouth, and *H* a little farther south at the entrance of the Rappahannock River. The salinities of the water ranged from 13.19 per mille at area *N* to 21.10 per mille at area *J*.

Hemiseptella denticulata was found at many areas in the lower half of the bay but not north of area *L*. It was collected from water ranging in salinity from 14.72 to 26.44 per mille.

Undoubtedly the presence of solid objects upon which the Bryozoa may attach themselves constitutes an important factor affecting the distribution; but the apparent confinement of one species, at least, to the region of the mouth of the bay, the taking of one only from the waters around the mouth of the Potomac River with the reports of a slightly brackish habitat for this species in other regions of the Atlantic coast, and the total lack of specimens in our collection of over 70 colonies from above area *S* indicate that the degree of salinity is a factor in determining the distribution. At least, as Osburn has stated, no specimens were taken in waters of a salinity lower than one-third of the salinity of pure sea water. Not much can be said concerning the influence of temperature, but several of the species seem to be able to withstand the winter and summer extremes of temperature found in the offshore waters at the bottom (about 2° to 25° C.).

The salinities given in this section on the Bryozoa are those determined from bottom samples; and they are probably the ones in which the various specimens were growing; but in some cases the specimens were taken on old hydroid stems which may have been unattached to the bottom but probably drifting about very close to it.

ANNELIDA

The collection of polychaetous annelids is rather small, but this is largely due to the fact that all of the material was dredged and to the fact that only the offshore waters of the bay were studied.

The species listed below were collected during the August, October, December (1920), and January, March–April (1921) cruises. All of the identifications were made by Dr. A. L. Treadwell. The following species have been identified by him (three of the species are new): *Lepidonotus squamatus* Linnaeus, *L. variabilis* Webster, *Harmothoe aculeata* Andrews, *Paranaitis speciosa* Webster, *Nephthys ingens* Stimpson, *N. phyllocirra* Ehlers, *N. verrilli* McIntosh, *Sphaerosyllis fortuita* Webster, *Pionosyllis manca*[9] Treadwell, *Myriana cirrata*[9] Treadwell, *Autolytus hesperidium* Claparède, *A. solitarius* Webster and Benedict, *Nereis dumerilii* Audouin et Milne Edwards, *N. limbata* Ehlers, *Lumbrinereis tenuis* Verrill, *Arabella opalina* Verrill, *Diopatra cuprea* Claparède, *Chaetopterus variopedatus* Renieri, *Streblospio benedicti* Webster, *Scolecolepis viridis* Verrill, *S. tenuis* Verrill, *Polydora ligni* Webster, *P. commensalis* Andrews, *Prinospio plumosa*[9] Treadwell, *Ammotrypane maculata* Webster, *Glycera americana* Leidy, *G. dibranchiata* Ehlers, *Goniada oculata* Treadwell, *G. solitaria* Webster, *Anthostoma fragile* Verrill, *Pectinaria gouldii* Verrill, *Maldane elongata* Verrill, *Praxiothea torquata* Leidy, *Eupomatus dianthus* Verrill, *Terebella ornata* Leidy, and *Loima turgida* Andrews.

The European species, *Lepidonotus squamatus*, is widely distributed along the eastern coast of North America—from Canada to Virginia at least. In Chesapeake Bay it was found no farther north than the mouth of the Potomac River and in water of not less than 20.00 per mille salinity at the bottom.[10] This species which was most prevalent on sandy, shell, and gravel bottoms at Woods Hole (Sumner, Osburn, and Cole, 1913, p. 120) was found in regions of sand, shells, and mud in the Chesapeake and at depths ranging from 13 to 37 meters. It was collected on the July, December (1920) and January (1921) cruises in water whose temperature varied from 22.0° C. to 4.2° C.

Lepidonotus variabilis seems to be less widely distributed so far as reports go, than *L. squamatus*. Apparently it has a more southerly range, having been reported, so far, from Virginia and North Carolina. In Chesapeake Bay it was found in several regions (depths 11 to 46 meters) from the mouth of the bay to the mouth of the Magothy River, near Baltimore. The salinities varied from 16.50 to 25.23 per mille. Some of our specimens were collected in muddy regions, but the observations of Andrews (1891) show that this species frequents shells, sponges, hydroids, etc., at Beaufort, N. C. This species was taken during the July, December (1920) and March–April (1921) cruises at water temperatures ranging from 21.9° to 10.3° C.

The "scale-annelid," *Harmothoe aculeata* which has been found in Beaufort, N. C., under stones and in sponges, by Andrews (1891) was taken in the lower part of Chesapeake Bay on several occasions, and once outside of the bay, in regions of sand or mainly sand and shells. The salinities ranged from 17.70 to 31.08 per mille. Specimens were captured during the July, August, and December cruises of 1920 in water whose temperature varied from 24.8° to 10.1° C. They were taken in depths from 8 to 28 meters and more.

Paranaitis speciosa (*Anaitis speciosa*) has been reported from Massachusetts and New Jersey, where it was found on Mytilus beds and Diopatra tubes. Our dredging records show that it is common in Chesapeake Bay, in regions where the bottom is firm. It was collected from a region extending from Baltimore to the mouth of the Rappahannock River, and was found frequenting shallow waters, ranging from 9 to 22 meters in depth. It was taken during the July, October (1920), and January, March–April (1921) cruises in water of various temperatures, ranging from 23.5° C. to 1.3° C.

The genus Nephthys is represented in Chesapeake Bay by three species, *Nephthys ingens*, *N. phyllocirra*, and *N. verrilli* (the two latter European forms). Evidently they are not common species in the region investigated, since only one or two specimens of each were collected.

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[9] Named and described by Treadwell but still unpublished.

[10] The salinities mentioned in this section on the Annelida are those at the bottom.

Sphaerosyllis fortuita and *Pionosyllis manca* (a new species) are represented by single specimens taken just outside of the bay.

A new species, *Myriana cirrata*, was taken frequently in the extreme southern part of the bay (areas *A*, *E*, *F*, and *G*) during the July, August (1920), and the March-April (1921) cruises. It occurred in water that varied in salinity and temperature from 25.23 to 30.39 per mille and 11.5° C. to 21.9° C. It was found at various depths from 16 to 46 meters. The bottom in this region was largely of sand and mud, with some shells.

The two species of Autolytus were not found abundantly. Of these, *Autolytus hesperidium*, which has been reported previously from New Jersey and Virginia living on seaweed and shells, was collected on one occasion only. It was taken from area *D*, off New Point Comfort, during the January 1921 cruise. The depth was 10 meters, and the salinity and temperature of the water were 23.39 per mille and 4.8° C. The other species *A. solitarius*, has been reported heretofore only from Maine. In the Chesapeake it was dredged in the mouth of the bay and off Barren Island, which is about midway between the head and the mouth of the bay. Evidently it is able to live in waters of widely differing salinities and temperatures. It was collected during the October 1920 cruise at depths ranging from 23 to 48 meters.

Nereis dumerilii, a European form, which has been collected along the Atlantic coast of America from the coast of Virginia and from the region of Woods Hole, was found in the lower half of Chesapeake Bay. It was collected from these localities (areas *O*, *F*, and *B*) during the July, August, and October (1920) cruises. The records show that the specimens collected were living in water the salinity and temperature of which ranged from 17.70 to 31.08 per mille and 17.3° C. to 24.8° C. They were dredged from depths of 8 to 48 meters.

Nereis limbata, which is generally considered as a littoral form frequenting foul and brackish waters (Sumner, Osburn, and Cole, 1913, p. 124), was the most common annelid in the Chesapeake collection according to Treadwell. It has been reported from various places from South Carolina to Maine. Webster (1879, p. 36) considers it as the only annelid that can live in the soft mud of brackish-water regions. In the Chesapeake it was taken many times at areas which were in the upper half of the bay. Only in a few cases were specimens captured near the mouth of the bay. Apparently this species thrives in muddy regions in Chesapeake Bay, but it has been taken also from some areas where the bottom was sandy or shelly. Almost invariably the specimens were found in water the salinity of which was not more than 20.00 per mille (9.00 to 20.00 per mille) but in a few cases the salinity was higher. *N. limbata* was taken many times during each of the cruises (July, August, October, December, 1920, and January, March–April, 1921) in water varying from 1.9° C. to 25.2° C. Most of the specimens were found in shallow water, seldom deeper than 15 meters, but the whole series of depths ranges between 7 and 38 meters.

Lumbrineries tenuis is an inhabitant of compact mixtures of mud and sand according to Verrill (1873, p. 342), who found it abundant in the region of Vineyard Sound. It has been reported from several localities (Virginia to Massachusetts), but in small numbers. No specimens were dredged inside of the bay, but just outside on the 20-fathom line one specimen was taken in August, 1920, in water of 33.58 per mille salinity and 8.9° C. temperature.

Arabella opalina, which has been found commonly along the Atlantic coast of the United States and in great numbers in quiet bays and creeks (Andrews, 1891), was dredged once only in Chesapeake Bay, and then at area *G* in the mouth of the bay. It was found at a depth of 23 meters in a region of black mud and sand during the December, 1920, cruise. (Salinity 30.96 per mille, water temperature 11.6° C.).

The large tube-inhabiting annelid *Diopatra cuprea* is undoubtedly a common form on muddy sand flats in Chesapeake Bay, since it is known to be common in shallow waters along the coast from South Carolina to Cape Cod (Pratt, 1916, p. 290). Our collections were made by dredging in the comparatively deep parts of the bay; and since it is seldom possible to catch this worm except by careful digging, it is not surprising that only one specimen was obtained. This one, strange to say, was collected in the beam trawl which contained in addition a large quantity of specimens of various sorts. It was taken during the March–April cruise, 1921, at area *A* off Cape Charles City where there was considerable black mud—in other words, in one of the "deep holes" of the bay (43 meters). The salinity and temperature of the water were 28.27 per mille and 11.5° C.

Another tube-dwelling annelid that has been found along our Atlantic coast from North Carolina to Cape Cod and which, as Treadwell has pointed out, is difficult to capture, is *Chaetopterus*. It undoubtedly is fairly abundant in Chesapeake Bay, for many fragments of tubes (one with a piece of the worm inside) were collected. These were all taken in the lower half of the bay from the mouth of the Potomac River to the region of Cape Charles (areas *Q*, *O*, *C*, *B*, *A*, *E*, *F*, and *G*). The salinities and temperatures of the water in which the tubes were found ranged from 17.70 to 28.08 per mille and 10.1° C. to 24.8° C.

Streblospio benedicti has been reported by Webster (1886, p. 150) and by Webster and Benedict (1884, p. 728) from the shores of New Jersey and Maine. Our survey has dredged it from the upper part of Chesapeake Bay, in shallow water only (10 to 22 meters). Webster has spoken of it as being abundant on Mytilus beds and in ditches to which the tide has access. The indications are, judging from these observations and from the fact that this species was found as far north as Bloody Point (areas *V* and *W*) in Chesapeake Bay, that it is at home in brackish water. The salinities of the water in which the six specimens in our collection were found ranged from 10.08 to 17.27 per mille. They were dredged during the July and October cruises in water whose temperature was 20° C. to 23° C.

Two species of *Scolecolepis* (*Scolecolepis viridis* and *S. tenuis*) are known from the Chesapeake. The former occurs in large numbers within a small area in certain places (for example, area *V*, which is close to the mouth of the Severn River). This species is known from Cape Cod to New Jersey. Evidently it can live in water of low salinity, for all of the specimens collected by our survey came from water the salinity of which was not more than 16.60 per mille. Specimens were especially abundant at an area where the salinity was as low as 9.16 per mille. Specimens were collected on the January and March–April, 1921, cruises when the water temperature was as low as 1.3° C. Only a few small specimens of *S. tenuis* were collected, and these came from area *B* not very far from the mouth of the bay (salinity 23.87 per mille, temperature 20.0° C., October, 1920).

Large numbers of specimens of *Polydora ligni* were collected. Treadwell speaks of this species as being "the species represented by the largest number of individuals in the collection." Many of the specimens were larval forms, however, and even the adults did not seem to be sexually mature. The larval forms were found distributed all over the bay, but those which had reached the adult form seemed to be restricted to the lower half.

One specimen was collected of a species of Polydora, probably Andrews' *Polydora commensalis*, since, although mutilated, it showed one of the distinguishing characteristics of that species. Furthermore, it was found in a region of shells, mud, and sand where this species might occur. The specimen was collected well up in the bay at area *R'* off the mouth of the Patuxent River. (Depth 7 meters, salinity 12.64 per mille, temperature of water 23.9° C., August, 1920, cruise.)

Treadwell describes a new species, *Prinospio plumosa*. A number of specimens of this annelid were dredged during the August and October, 1920, cruises (depths from 8 to 48 meters) at areas *R*, *R'*, *L'*, *M*, *N'*, *H'*, and *J*. It will be seen that specimens were taken from the middle third of the bay—that is, from the mouth of the Patuxent River to the mouth of the Rappahannock River in waters where the salinities and temperatures ranged from 15.39 to 25.21 per mille and 19.2° C. to 24.8° C.

Glycera americana, which has been reported in various places from South Carolina to Cape Cod, was caught on one occasion only in Chesapeake Bay. Two specimens were taken at area *B* in the lower bay during the August, 1920, cruise. (Depth 12.8 meters, salinity 24.34 per mille, and temperature 25° C.) Another species of Glycera, *G. dibranchiata*, was more widely distributed, judging from our collections. It was found in the mouth of the bay and as far north as the mouth of the Patuxent River at depths of 16 to 46 meters. The salinities and temperatures ranged from 16.60 to 31.74 per mille and 10.2° C. to 17.3° C.

Goniada oculata described by Treadwell from material collected on the coast of Porto Rico was taken quite frequently in Chesapeake Bay during the cruises of August, October, December, 1920, and March–April, 1921. It was found at depths from 11 to 46 meters where the salinity and temperature of the water ranged from 15.00 to 23.87 per mille and 10.1° C. to 24.8° C. One specimen (the above data do not refer to it) was taken on the 40-fathom line just outside of the bay and the rest from areas distributed from James Island to the mouth; that is, the lower two-thirds of the bay.

Another widely distributed annelid in Chesapeake Bay is *Pectinaria gouldii*—an annelid that lives in a tube of conical shape. It was brought up from areas *Z*, *S*, *N'*, *J*, *I*, *Q*, and *D*, which are fairly well distributed from the mouth of the Magothy River to the region of Cape Charles City, not far from the mouth of the bay. It was taken at depths from 8 to 44 meters where the salinities and temperatures of the water were from 8.89 to 21.83 per mille and 7.5° C. to 24.8° C. The specimens were collected during the July, August, October, December, 1920, and the March–April, 1921, cruises.

Maldane elongata, which makes tubes of mud and which has been reported from muddy and sandy regions along our coast, was found in the mouth of the bay (area *G*) where the bottom was black mud and sand. It was brought up from a depth of 23 meters. The salinity and temperature of the water were 30.96 per mille and 11.6° C.

Praxiothea torquata was taken on several occasions in Chesapeake Bay, but all of the specimens collected were found in the mouth of the bay and the adjacent regions. They were collected from depths of 11 to 42 meters where the salinities and temperatures of the water ranged from 23.87 to 30.96 per mille and 10.9° C. to 25.0° C.

Three species, *Eupomatus dianthus*, *Terebella ornata*, and *Loimia turgida*, were collected in very small numbers and only from the lower part of the bay. The first is one of the serpulids which is known to be very common from Florida to Cape Cod. It was found on a rocky bottom at 13 meters. (Salinity 18.47 per mille and temperature of water 23.2° C., July, 1920, cruise.) The second, which is known from Cape Cod to North Carolina, was represented only by immature forms. The third, which was described by Andrews from Beaufort, N. C., came from a depth of 28 meters where the bottom was a mixture of clay, shells, sand, and mud. (Salinity (?) and temperature of the water 10.1° C., December, 1920, cruise.)

The annelid collection as well as the data on salinity, temperature, depth, character of the bottom, seasonal distribution, and distribution from the head of Chesapeake Bay to its mouth, deal with the deeper portions of that body of water, which naturally were the only regions that could be visited by the U. S. S. *Fishhawk* and the U. S. S. *Albatross*. The shore which includes the more or less steep strip between high and low tide, the sand flats, the mud flats, the quiet bays, etc., remain to be investigated.

It seems probable that the character of the bottom for some burrowing and tube-forming annelids is important—at least regions where there is deep, soft, foul mud are unfavorable habitats for nearly all of the polychaetous annelids. Some places on the bottom of the bay are covered with such deposits; and, in general, the deeper parts of the bay show a layer of firm mud of varying thickness. It is of interest to note that the only two really common annelids taken in the bay, *Nereis limbata* and *Polydora ligni*, are known to live in muddy regions, the former frequenting foul and brackish waters and the latter making use of mud in constructing its fragile tubes. Both of these species showed a wide distribution over the areas visited on our cruises. On the other hand, there are regions of sand here and there all over the bay, so that if the presence of these sandy places is all that is necessary for the life of worms that make tubes of grains of sand, such annelids might be found widely distributed over the bay.

It is known that many annelids live on the organic matter which is found in the sand or mud in which they burrow (M'Intosh, 1885, p. ix), as in the case of *Arenicola marina* (Flattely and Walton, 1922, p. 192, from Davison, 1891), that others such as *Cirratulus tentaculatus* (Flattely, 1916) while living buried in sandy mud do not pass it through the alimentary canal but select nutritive food particles—for example, algal spores, diatoms, and general organic débris outside of the body. Also it is known, according to Flattely (1922, p. 192), that tube worms such as Sabella, Pectinaria, Sabellaria, Serpula, etc., depend for their food on currents set up by the cilia on the gill filaments. Still others devour small crustaceans, zoophytes, and sponges; and a few, according to M'Intosh (1885, p. ix), feed on Fuci and other algæ. Such a variety of feeding habits must be a factor in the distribution of the polychaetous annelids in Chesapeake Bay, although our data are not of a character to throw much light on such a relation. Shore, sand-flat, and mud-flat observations should be ideal for studying a problem of that sort.

There are forms which stick to the underside of rocks and inside of shells, or hide in rocks and crevices, or conceal themselves between ascidians, barnacles, roots, cavities of sponges, etc., such as species of Lepidonotus, Harmothoe, and others (Verrill and Smith, 1873, p. 397).

Also some annelids, such as species of Sabellaria, Serpula, Sabella and Spirorbis, form tubes which are attached ordinarily to rocks, stones, shells, etc. (Verrill and Smith, 1873, pp. 321–323). Habits of this sort which depend on the presence of large more or less stationary bottom materials must also have an effect on distribution.

No close relationship of distribution to temperature can be made out, although the data show that many of the species are able to live in water of a wide range of temperatures. However, the large majority of the forms collected seem to be more southern forms.

It is evident, also, that many of the species of annelids are distributed through waters of widely differing salinities, as examples, *Nereis limbata*, *Goniada oculata*, *Pectinaria gouldii*, and others.

Undoubtedly some of the annelids collected were living in situations which were not well suited to them, since the currents during fall and spring tend to carry plankton, including worm larvæ, far up in the bay. Under those conditions a worm which lives at its best in water of a high salinity might have its larvæ carried to regions of low salinity where they would settle down and continue to live, although under unfavorable conditions.

Only one species representing the Hirudinea has been taken in our collections, and this one has been identified through the courtesy of Dr. J. Percy Moore, as the fish-leech, *Piscicola punctata* (Verrill).

ARTHROPODA

CRUSTACEA

COPEPODA

The free-swimming copepods of Chesapeake Bay and the region immediately outside the bay have been studied by C. B. Wilson. He has made the identifications and has studied the distribution of the various species.

The results of his work show very clearly that only two or three species were present in sufficient numbers in the bay during our cruises to be of much economic value; that of these, 2 species, *Acartia clausii* and *A. longiremis*, were distributed over the whole bay from the region of Baltimore to the mouth of the bay throughout the year; that 10 species at least, including especially the 2 just mentioned, must have been able to accommodate themselves to a large range of salinities, since they were found all over the bay in addition to the ocean; and that there were 19 species caught outside of the bay between the 100-fathom line and the mouth, which were not discovered in our very numerous towings made throughout the year in the bay. The absence of these 19 species, which for the large part have been found outside of such bodies of water as Chesapeake Bay in other parts of the world, may be ascribed to the low salinity existing in the bay; but it is not possible at the present time to establish such an assumption absolutely as a fact, since our towings outside of the bay were made only during the August, 1920, cruise. Furthermore, there are numerous other factors, such as presence or lack of the proper kind of food, associations with other forms—for example, *Sapphirina gemma*, which is a commensal in Salpa, light, depth, temperature, etc.—which might have to be taken into consideration.

Wilson's studies have brought to light the following species from Chesapeake Bay and the region just outside of the capes. He has divided them into groups according to their distribution.

UNIVERSAL IN BAY AND OUTSIDE

Acartia clausii Giesbrecht, *A. longiremis* (Lilljeborg), *Centropages hamatus* (Lilljeborg), *C. typicus* Krøyer, **Harpacticus gracilis* Claus, *Oithona brevicornis* Giesbrecht, *O. similis* Claus, *Paracalanus parvus* (Claus), *Pseudocalanus elongatus* (Boeck), *Pseudodiaptomus coronatus* Williams, and **Microthalestris littoralis* G. O. Sars (the last species is pronouncedly littoral and was not found in the collections made outside). Two other species, *Labidocera aestiva* Wheeler and *Ectinosoma curticorne* Boeck, were almost universally distributed.

CONFINED ALMOST TO INNER BAY

[North of Maryland and Virginia line]

**Canuella elongata* Wilson, **Cletodes longicaudatus* (Boeck), **Dactylopusia brevicornis* (Claus), *Ectinosoma normani* T. and A. Scott, *Harpacticus littoralis* G. O. Sars, **Robertsonia chesapeakensis* Wilson, **Tachidius littoralis* Poppe, *Eurytemora americana* Williams, *E. hirundoides* (Nordquist), and **Mesocyclops gracilis* (Lilljeborg). Three other species, **Hemicyclops americanus* Wilson, *Candacia armata* Boeck, and **Bomolochus eminens* Wilson occurred in very small numbers at one or two areas.

CONFINED ALMOST TO OUTER BAY

[South of Maryland and Virginia line]

Alteutha depressa Baird, *Calanus finmarchicus* (Gunnerus), *Corycaeus carinatus* Giesbrecht, *C. elongatus* Claus, **C. venustus* Dana, **Cryptopontius gracilis* Wilson, **Oithona spinirostris* Claus, *Oncaea minuta* Giesbrecht, **Labidocera wollastoni* (Lubbock), *Pontella meadii* Wheeler, *Temora longicornis* (Müller), **T. turbinata* (Dana), *Tisbe furcata* (Baird), *Microsetella norvegica* (Boeck), *Harpacticus chelifer* (O. F. Müller), and *Diosaccus tenuicornis* (Claus). In addition the following species, in very small numbers, were found at one or two areas: **Temora discaudata* Giesbrecht, *Pontella pennata* Wilson, and *Caligus schistonyx* Wilson.

FOUND ONLY OUTSIDE OF THE BAY

[Between the capes and the 100-fathom line]

**Amallophora brevicornis* G. O. Sars, *Anomalocera patersoni* Templeton, **Calanus helgolandicus* (Claus), *Centropages bradyi* Wheeler, *Euchaeta norvegica* Boeck, *Mecynocera clausii* I. C. Thompson, *Metridia lucens* Boeck, **Pontella atlantica* (Milne Edwards), *Rhincalanus nasutus* Giesbrecht, *Clytemnestra rostrata* (Brady), *Macrosetella gracilis* (Dana), **Corycaeus lubbockii* Giesbrecht, **C. speciosus* Dana, *Oithona plumifera* Baird, *Oncaea venusta* Philippi, *Sapphirina gemma* Dana, and **S. sinuicauda* Brady, *Corycaeus robustus* Giesbrecht, *C. rostratus* Claus.

These lists total 64 species: 13 universal, or almost so, over the bay; 13 almost confined to the inner bay; 19 almost confined to the outer bay; and 19 outside of the bay only. Not less than 19 of the 26 species listed under "universal" and "inner bay" occur in such bodies of water as Chesapeake Bay or at least frequent coastal waters in other parts of the world, and these 19 do not include the new species and the species whose distribution is very little known. Of those listed under "outer bay" (19) a much smaller number (6) are characteristic of estuaries in other regions, while those listed for "outside of the bay" (19) include not more than 3 or 4 species which are recorded as being estuarine forms. In other words, the number of estuarine forms found during our cruises decreases, passing from the inner bay to the region outside of the capes. On the whole, from this point of view, the distribution of the free-swimming copepods found by us in Chesapeake Bay and the region immediately outside of the bay is much like that of the same copepods in other parts of the world.

Twenty-two of the species listed above (those with an asterisk) are either new species (named and described by Wilson but still unpublished) or those which have not been reported hitherto from the eastern coast of North America.

There are included in the complete list 1 species, *Bomolochus eminens*, which is known to occur parasitically in the gill cavity of the false Spanish sardine, *Clupanodon pseudohispanicus;* 1 species, *Sapphirina gemma*, caught free-swimming but known to be a commensal in Salpa; 1 species, *S. sinuicauda*, also caught free-swimming but probably a commensal in Salpa; 1 species, *Caligus shistonyx*, an external parasite on the menhaden, *Brevoortia tyrannus;* and 1 species, *Mesocyclops gracilis* which is a fresh-water form.

Most of the copepods caught in Chesapeake Bay have been present in such small numbers that any extended discussion of their ecology is not permissible; but one species especially, *Acartia clausii*, which Wilson has singled out as of much biological and economic importance in the bay, owing to its abundance at times and constant presence during our cruises, deserves some attention. The catches of this copepod have been studied by Wilson, and his findings bear out the statements of Farran (1910, p. 77), Willey (1920, p. 201 and 1921, p. 187), and Bigelow (1926, p. 171) with respect to the neritic character of this species. Its occurrence in Chesapeake Bay during the cruises of July, August, October, December, 1920, and January, March–April, and May–June, 1921, in rather large numbers at practically all areas, the presence of egg-bearing females and larval stages at certain times, the high percentage of this species in the copepod catches, and its comparative scarcity in oceanic waters indicate that this form is one of the shallower, neritic waters and that it is endemic in Chesapeake Bay.

This form has been found along our coasts as far north as the Arctic Circle by Willey (1920, p. 20 K), in the St. Lawrence River 90 miles from Quebec by Herdman, Thompson, and Scott (1898, p. 76), in the Gulf of St. Lawrence by Scott (1907, p. 49), in Narragansett Bay by Williams (1906, p. 648), in the Gulf of Maine by Bigelow (1926, p. 171), in Woods Hole by Fish (1925, p. 145), and by our survey in and immediately outside of Chesapeake Bay. The data are not sufficient as yet to tell whether it belongs primarily to the northern or southern regions of our Atlantic coast. Bigelow's cruises from Cape Cod to Chesapeake Bay in 1913 and 1916 did not bring it to light, but it was found in small numbers outside of the mouth of Chesapeake Bay on our August, 1920, cruise and at the same time much more abundantly at nearly all of the areas in Chesapeake Bay.

Wilson, from an examination of the females of *Acartia clausii* (and *A. longiremis* as well) found that during the July, 1920, cruise these forms were carrying eggs, and that the same was true on the January, 1921, cruise. This indicates, as he states, that there are two breeding seasons for these species in Chesapeake Bay—one during the summer and the other in the late winter. Correlated with these two breeding seasons one would expect maximum numbers of individuals to appear some time after. Judging from the catches made during the March–April, 1921, cruise, conspicuously large numbers occurred at that time, since the counts at several of the areas visited were very much higher than those of any other cruises. It should be mentioned, however, that towings were made only in the upper part of the bay—areas *R*, *R′*, *S*, *T*, *V*, *W*, *Y*, and *Z*—on that cruise. The indications are that the March–April cruise was taken at a time which was close to the spring maximum. It is more difficult to detect a well-defined autumnal increase corresponding to the summer breeding season from a study of the catches, but there was undoubtedly a general increase in numbers during the October, December, 1920, and January, 1921, cruises, so that the seasonal abundance in the upper part of Chesapeake Bay at least corresponds rather closely to the seasonal occurrence found by Fish (1925, p. 145) at Woods Hole during the period from June, 1922, to May, 1923. The counts made of the catches of the summer cruises were the lowest of the year.

Little can be said of the vertical distribution of *Acartia clausii* in the bay, owing to the methods employed in making the towings, but it is clear that large numbers of this species may occur at the surface in the daytime; and it is probable, as Wilson states, that they may be distributed in various proportions from the surface to the bottom. Bigelow (1926, p. 175) has found this species more abundant at the surface at times but also repeatedly more plentiful at some deeper level in the Gulf of Maine.

Acartia clausii has been recognized in Europe as a form which is able to flourish in abundance in water of low salinity such as is found in the Belt Sea, where the average of 8 stations was 18.42 per mille, and in the mouth of the English Channel, where the average for 17 stations was 30.20 per mille (Farran, 1910, p. 77). One can not escape the conclusions that this copepod, as is shown by Wilson, may be found abundantly and in good condition in waters of even much lower salinity in Chesapeake Bay. As examples, the bottom net showed the following counts in round numbers during the March–April, 1921, cruise: Area *Z*, 75,000 (salinity $<$12.42 per mille); *V*, 17,500 (salinity $<$9.17 per mille); *T*, 15,000 (salinity $<$11.51 per mille); *S*, 60,000 (salinity $<$16.19 per mille); *R′*, 2,900 (salinity $<$11.85 per mille); and *R*, 1,400 (salinity $<$16.61 per mille). The specimens captured in the upper bay during this cruise can not be considered as *only* immigrants which had drifted in with the autumnal and winter currents, for individuals were found at those same areas, although in smaller numbers, on all the other cruises. In addition, they were found at all areas visited, and these were very numerous and widely distributed. *Acartia clausii* was practically universal in occurrence over the bay and on all the cruises with the possible exception of the one made in March–April, 1921. Even on this cruise the same would hold true, for the upper part of the bay (areas *R*, *R′*, *S*, *T*, *V*, and *Z*) and very probably for the whole bay. Our data do not show higher surface counts for *Acartia clausii* in the region of the mouths of rivers; nor can it be said that there were larger numbers on one side of the bay than the other, corresponding possibly to a difference in the degree of salinity. The data for the bottom samples are not suitable for such a comparison.

The European records (Giesbrecht, 1892, p. 776; Scott, 1894, p. 68; Sars, 1903, p. 151, and Farran, 1910, p. 77) show that *Acartia clausii* is distributed in the cold and the warm water regions. While specimens of this species are found most abundantly in Chesapeake Bay during the colder months, considerable numbers are present at other times, and the records show that they may occur in waters which range in temperature from at least 4° C. to 27° C.

CIRRIPEDIA

Two species of barnacles have been brought to light from the offshore waters of Chesapeake Bay: *Balanus improvisus* Darwin and *B. eburneus* Gould. All of the specimens collected during the cruises of August, October, December, 1920, and January, 1921, were identified by Dr. H. A. Pilsbry at the request of the United States National Museum.

The first species, *Balanus improvisus*, was taken by far the most frequently and was found distributed from the mouth of the bay to as far north as area *S* off James Island. It was collected from the following areas: *G*, *G′*, *F*, *C*, *D*, *A*, *Q*, *O*, *M*, and *N′*. At the latter area, which is in the mouth of the Potomac River, the specimen obtained was living in water of a salinity that was not more than 13.96 per mille, while specimens at area *G* (in the mouth of the bay) were in water whose salinity was not more than 31.74 per mille.

This form is given a wide distribution both by Darwin (1854) and by Gruvel (1905). The latter describes its distribution as along the English Channel, the coasts of France, Patagonia, Colombia, in the Rio de la Plata, and along the coast of the United States. It has also been reported from Nova Scotia. Sumner, Osburn, and Cole (1913, p. 130) point out that definite localities for its occurrence in the

United States have not been mentioned by the authors and express the belief that it occurs at Woods Hole. The indications are that this barnacle is a southern form.

Ordinarily, *Balanus improvisus* has been found attached to floating wood, shells, etc. In the Chesapeake it has been taken at areas where the depths ranged from 10 to 46 meters; and in other parts of the world, according to Gruvel (1905, p. 231), it has been found from the level of low tide to 35 or 40 meters.

Judging from the literature, *Balanus improvisus* is not commonly found along the coast of the United States, but it seems quite probable that further investigation will show it to be much more abundant than the records indicate at the present time.

Balanus eburneus is a species which is generally recognized as a brackish-water form. It was originally described by Gould (1841) from Salem, Mass., and is known to occur in other places along the coast of the United States. According to Gruvel (1905, p. 234) it has been found on the coast of Honduras, Venezuela, Jamaica, and Trinidad. In Chesapeake Bay it was collected near the mouth of the Potomac River at areas *Q* and *O* where the bottom salinity was 20.58 and 20.91 per mille, respectively. The depths at these areas were 15 and 8 meters. This species seems to be a southern form.

It is evident from our records that barnacles occur well up in Chesapeake Bay, but shore collecting undertaken by the writer has shown that there is at least one species still unidentified which is quite abundant on piles and other objects and that it flourishes as far up Chesapeake Bay as the mouth of the Patapsco River and probably farther. In this region the salinity may fall so low during the spring months that the water is almost fresh.

AMPHIPODA

The species of amphipods which are listed below represent the catch made during a single cruise, that of May, 1920. These have been identified by C. R. Shoemaker, of the division of marine invertebrates of the National Museum. A considerable amount of material collected on other cruises still awaits study so that undoubtedly more species will come to light when this is done. However, it has been the experience of those who undertook the survey of the Woods Hole region that in Buzzards Bay, which is a body of water much like Chesapeake Bay, the collections of bottom-dwelling amphipods showed a paucity of species as compared with Vineyard Sound (Sumner, Osburn, and Cole, 1913, p. 132).

The following is a list of the species: *Monoculodes edwardsi* Holmes, *Stenothoë cypris* Holmes, *Batea catharinensis* Müller, *Leptocheirus* species (new), *Ericthonius brasiliensis* (Dana), *Corophium cylindricum* (Say), *Cerapus tubularis* Say, *Paracaprella simplex* Mayer and *Caprella acutifrons* Latreille.

But little can be said of the relation of distribution to salinity, temperature, depth, season, or latitude at this time. However, the new species of Leptocheirus was found off Sandy Point, Md., where the bottom salinity was 5.76 per mille, and none of the rest of the species so far as we have records was taken at areas where the bottom salinity exceeded 21.00 per mille. These low salinities are accounted for by the fact that all of the specimens collected came from areas where the depths did not exceed 14 meters—in other words, from shallow water areas.

Monoculodes edwardsi was found at areas *L′* and *K′* not far from the mouth of the Potomac River. The bottom salinity at the first area was 13.09 per mille, and at the last 9.42 per mille. This species, which was described by Holmes (1905, p.487) from a specimen found at Woods Hole, Mass., was spoken of by him (1903, p.275) as having a distribution from Cape Cod to Cape Hatteras.

Another species described by Holmes from Woods Hole (1905, p. 484) is *Stenothoë cypris*, which was found by him upon the piles and among seaweeds and which was given a distribution like *Monoculodes edwardsi* (1903, p. 278). It was collected at areas *C* and *K*, the former off New Point Comfort and the latter near the mouth of the Potomac River. The bottom salinities at these two areas were 20.65 per mille, and 13.09 per mille, respectively.

The amphipod *Corophium cylindricum*, which lives in soft tubes but may be free (Holmes, 1905, p. 522) and which has a distribution from Cape Cod to Cape Hatteras, according to Holmes (1903, p. 288), was found at areas *B* and *C* between Cape Charles City and New Point Comfort (bottom salinity for area *C*, 20.65 per mille). Mary J. Rathbun (1905, p. 75) found it "very abundant among weeds and hydroids about piles of wharves and almost everywhere in shallow water, to a depth of 30 fathoms."

Cerapus tubularis is another amphipod of this coast distributed, according to Holmes (1903, p. 288), from Cape Cod to Cape Hatteras. This interesting amphipod lives in a black, cylindrical tube which it carries around with it, according to Smith (1880, pp. 274–276). The specimens from which the identification was made were found at area *B*, between New Point Comfort and Cape Charles City. The bottom salinity for this area during the cruise is not known, but the salinity for a nearby area (*C*) where the depth was about the same was 20.65 per mille.

A South Atlantic species described by Fritz Müller from the coast of Brazil is in our collection. It is *Batea catharinensis.* Specimens were taken at the two areas *B* and *C* in the same region as the last species and in water where the bottom salinity was 20.65 per mille for area *C* and probably very nearly the same for area *B*. Recently C. R. Shoemaker (1926, p. 1), after studying the complete collection of Chesapeake amphipods taken from 1915 to 1921, found that "this genus was common in almost every part of the bay."

In addition to this southern species, a widely distributed form, *Erichthonius brasiliensis* (Dana), occurs in the bay. The individuals of this species occupy tubes affixed to hydroids and algæ. According to Stebbing (1906, p. 672), the species is found in the "Atlantic with adjoining seas (Europe from south and west Norway (depth 19–75 meters) to Adriatic and Bosphorous; Rio Janeiro; Vineyard Sound); North Pacific (San Francisco, depth 4 meters)."

The specimens collected in Chesapeake Bay during the May cruise were found at area *C* (depth, 13 meters; bottom salinity, 20.65 per mille).

Another widely distributed amphipod which occurs in Chesapeake Bay is *Caprella acutifrons* Latreille which, according to Mayer (1890, p. 56), was found there long before the present survey, in August, 1879.

Finally, specimens of *Paracaprella simplex* Mayer were caught at areas *B* and *C* on the line between Cape Charles City and New Point Comfort. The depth at these areas was 13 meters and the bottom salinity at area *C*, 20.65 per mille.

The bottom salinities have been given for the areas at which specimens of amphipods were found; but it does not follow that all of the specimens were taken in waters of the salinities given, since specimens are not always at the bottom. While many live in the sand, under stones, and in crevices of sponges, ascidians, etc., and some among hydroids and various water plants, they may at times be taken at or near the surface in Chesapeake Bay, as our records show. Fish (1925) found a similar vertical distribution at Woods Hole. The bottom salinities are of value in this connection however, since they give a satisfactory idea of the maximum salinity for the area, so that specimens were probably living in water of lower salinity. No data are given as to temperature, since the thermometers used during that cruise were not of the reversing type which records bottom temperatures.

ISOPODA

As in the case of the amphipods, the species listed below were those taken on the May cruise, 1920. They probably represent only part of the species which have been collected in later cruises but which have not been studied. The list is as follows: *Aegathoa oculata* (Say), *Erichsonella attenuata* (Harger), *Edotea triloba* (Say), *Idothea baltica* (Pallas) and *Edotea montosa* (Stimpson).

The first species, *Aegathoa oculata*, is a parasitic form which is known from New England to the West Indies (Richardson, 1905, p. 217) and which was found at Crisfield, Md., years ago. We collected this form at area *B*, off Cape Charles City. No fish were caught at this station, and the records do not indicate that the specimen was attached to anything at the time of capture.

So far as records from various sources show, the isopod *Erichsonella attenuata* is not widely distributed. It is known to frequent eelgrass along the coast of New Jersey and Connecticut but, according to Harger (1878, p. 357), it has not been found north of Cape Cod. The studies of Wallace (1919), Macdonald (1912), and Stimpson (1853) do not show its occurrence along the Atlantic coast of Canada. During our May, 1920, cruise it was taken at area *Z*, not far from Baltimore. The salinity of the water in that region did not exceed 6.00 per mille. As pointed out by Harger, the known distribution of this form indicates that it is a southern form.

Edotea triloba, another isopod which Harger (1880, p. 429) speaks of as a southern form, since that time has been found very abundant in the Bay of Fundy between low-tide mark and 15 fathoms (Wallace, 1919). It has been collected along the coast from Maine to New Jersey in shallow water and was taken in Chesapeake Bay at areas *G* and *C*. The depths and bottom salinities at these areas were 24 meters, 25.77 per mille, and 13 meters, 20.65 per mille, respectively. Apparently it may be found on almost any sort of bottom.

The cosmopolitan isopod, *Idothea baltica*, has been found along the Atlantic coast of Canada and the United States as far south as North Carolina at least. In Chesapeake Bay it was caught at areas *A* and *B*, not far from the mouth of the bay. The depths at these areas were 13 meters and 40 meters; the salinities, 24.33 per mille and 29.34 per mille (at 39 meters), respectively.

Another species of Edotea, *E. montosa*, which is considered by Wallace (1919, p. 26) as grading into *E. triloba* and *E. acuta* and which has been known heretofore from Long Island Sound to the Bay of Fundy, was taken at area *A* under the same conditions as *Idothea baltica*. This species had been classed by Harger (1880, p. 429) as a northern form.

SCHIZOPODA

The Schizopoda are represented in Chesapeake Bay by the well-known species *Neomysis americana* (Smith), formerly called *Mysis americana*, and two other species—one *Mysidopsis bigellowi* Tattersall and another which will be designated as *Mysidopsis* sp. nov. until it has been studied and described by Doctor Tattersall. The last two species are quite uncommon in our collections, but *Neomysis americana* was taken on every cruise during the year (1920), and there is much evidence to indicate that it is endemic in Chesapeake Bay.

While catches of *Neomysis americana* in tow nets can never give a very satisfactory idea of the numbers present in Chesapeake Bay during different times of the year, since the individuals are not swarming in the water at all times but may be hidden among water plants, etc., yet the catches in the bottom net (nonclosing), which was attached to a small beam trawl and towed for 10 minutes, are of interest. During the January cruise the numbers brought to the surface were large—for example in round numbers, 1,000 at area *F*, 8,000 at area *B*, 5,500 at area *Q*, 7,000 at area *J* and 40 at area *R'*. No bottom hauls were made north of area *R'*, but the vertical nets showed the presence of Neomysis as far north as area *W* off Bloody Point. A similar distribution was found when the March cruise was taken, but the numbers were smaller. Very small catches (ordinarily less than 100 specimens) were obtained on the May, July, and August cruises except on one occasion at area *G* during the July cruise, when 4,000 specimens were caught. A few specimens were captured on the 100-fathom line just off the mouth of the bay during the August cruise. The counts were larger when the October and December cruises were taken than during the summer.

In January and March, 1920, the specimens collected were mostly of large size, but on the May cruise only small individuals were found. During the July, August, October, and December cruises the towings brought to light somewhat larger specimens. On the January and March–April cruises (1921) mostly very large specimens were caught, while on the May–June cruise (1921) the specimens were mostly small again as during the cruises of about the same periods in 1920.

These size relations are in keeping with the observation of Fish (1925) for Woods Hole, that *Neomysis americana* breeds in the winter. In fact, eggs and young and large specimens with brood sacs were taken during the January, 1920, cruise. The great majority of the specimens were large; only a few were small, and these were evidently recently hatched and immature. The conditions found on the March cruise were similar to those just mentioned, but in the May catches the large individuals were scarce. Some of these, however, had brood sacs containing very young larvæ. In the July towings the large specimens so characteristic of the earlier months of the year were not present, but on the other hand specimens of more than one-half the size of those large specimens (probably the partly grown young of the earlier months) made up the whole catch. Some of the specimens just mentioned had brood sacs filled with eggs, and there were a few larvæ present. During the October cruise the conditions were much as in July—eggs and young larvæ were found in the brood sacs and there were some very young specimens free from the parent. The material from the December cruise contained no individuals with eggs or with young, although in a few specimens the remains of a brood sac could be seen. The cruises of January, March–April, and May–June, 1921, showed the breeding conditions as on the January, March, and May cruises of 1920.

These observations indicate then that breeding individuals are present throughout most of the year in Chesapeake Bay, a condition which was thought likely by Smith (1879) when he studied Neomysis farther north.

It is evident from a study of large numbers of surface towings that Neomysis does not ordinarily frequent the surface waters in Chesapeake Bay during the daytime, but there is evidence to show that it may appear there in large numbers when the intensity of the light is low, even when there is a distinct stratification of the water and there is a large difference between the salinity of the surface and bottom layers. Only a few cases of this sort appear in our records, probably because towings were seldom made late in the evening and never during the night. At area *A*, during January, 1920, between 5 and 6 p. m., 250 specimens and 120 specimens were found in the No. 5 and No. 20 surface nets; at area *F*, during December, 1920, between 5 and 6 p. m., 1,380 specimens and 180 specimens were taken in the No. 18 and No. 6 surface nets; and at area *Q*, during January, 1921, between 5 and 6 p. m., 2 specimens and 2 specimens were caught in the No. 18 and No. 6 surface nets, respectively. On one occasion specimens were captured at the surface early in the afternoon (2 to 3 p. m.), but the sea was rolling, and the sky was partly cloudy and foggy. This occurred at area *G*, in October, 1920, and there were 7 specimens found in the No. 6 surface net.

It is evident from the records obtained by our survey and from the distribution found by other workers in more northern waters that *Neomysis americana* may live in waters of a wide range of salinities and temperature.

As a fish food this form is probably of considerable importance; for it has been found in the stomachs of the ocellated flounder, the spotted flounder, the shad, the mackerel, and sea herring, sometimes in great numbers. It is of interest that the period of maximum abundance during the year 1920, according to our towings, was in the early months of the year just before and at about the time when the migration of anadromous fishes into the bay occurred.

STOMATOPODA

The common squilla, *Chloridella empusa* (Say), formerly known as *Squilla empusa* Say, has been found in Chesapeake Bay. In June, 1880, it was collected by W. G. Taylor; in 1882 it was taken near Barren Island and also at stations 1075, 1076, 1077, and 1058 by the U. S. S. *Fish Hawk*; in October, 1921, it was found in the Rappahannock River by W. C. Schroeder, and again by the same collector in May, 1922, on a trip from Crisfield to Cape Charles. During our cruises a specimen was taken at area *D* in January, 1920. I am indebted for identification and other information to the division of marine invertebrates of the National Museum.

In addition to the specimens mentioned above, which were identified by the United States National Museum, other squillas were captured at areas *L*, *L′*, *H*, *R*, *X*, and *B* which undoubtedly are of the same species. They were collected during the cruises of March, April, July, 1916, and March, 1922, from areas distributed from near Cape Charles City, not far from the mouth of the bay, to area *X*, off Bloody Point. It is evident from the distribution of this crustacean in Chesapeake Bay that it may live in water of widely differing salinities—approximately, according to our records, from 26.00 per mille or a little more to 16 or a little less. Undoubtedly this form lives also in water of a much higher salinity, for it is known to occur along the shores of the open ocean.

Since *Chloridella empusa* lives in other regions between the tide lines and in shallow water and since it is a burrowing form, probably its distribution in Chesapeake Bay is more extensive than our records show.

CUMACEA

One Chesapeake species of Cumacea has been identified by the United States National Museum as probably *Oxyurostylis smithi* Calman. This crustacean, for which Calman (1912, p. 676) made a new genus as well as species, is known from Casco Bay, Me., to Calcassieu Pass, La. The fact that it is sometimes taken at the surface and that it has only a slightly calcified integument suggests to Calman that it is adapted for a partly pelagic life. Fish (1925, p. 152) found it in the plankton in greater numbers during the breeding season and most abundant usually after a storm.

Ten specimens were captured at area *K*, off the mouth of the Potomac River, in May, 1920. It is not known at what depth they were taken; but the bay at that area was 10 meters deep, and the bottom was of yellow sand. The salinity ranged from 11.15 per mille at the surface to 13.09 per mille at the bottom.

DECAPODA

The Chesapeake survey is fortunate in having the aid of the United States National Museum for the identification of the decapod crustacea. It is indebted to the division of marine invertebrates of that institution, and especially to Dr. Mary J. Rathbun and to Dr. Waldo L. Schmitt, who have generously studied, identified, and listed the various decapods collected on our cruises.

It is important to note that the lists given below not only include the specimens taken by the Chesapeake survey but also those which have been collected from Chesapeake Bay and vicinity during the last 50 years. These specimens have been deposited in the United States National Museum and identified by its staff. Consequently, the material has been collected in various ways, such as by dredging, trawling, and towing in the offshore waters, by seining near shore, by collecting along the tide lines, by collecting in marshes, rivers, and creeks connected with Chesapeake Bay, and by dredging, trawling, and towing immediately outside of the mouth of Chesapeake Bay.

The three lists which follow deal with Chesapeake Bay only and are little more than records of the names of species and the regions in which they have been found. They are not intended to show the limits of distribution, since much of the material is not the result of systematic collecting over the whole bay. The distribution of species in Chesapeke Bay, so far as the author considers permissible from the data, will be given in other lists.

Upper bay only (*north of the mouth of the Potomac River*).—One species of decapod, *Pinnixa sayana* Stimpson, was taken from the upper part of the bay and from no other region. The records in this case show that it was collected only on two occasions. Since this species probably lives in the tubes of annelids and since no special effort was made to find it, the data are insufficient to draw any conclusions as to its distribution.

Lower bay only.—Shrimps: *Penaeus setifera* (L), *P. brasiliensis* (Latr.) (probably), *Trachypenaeus constrictus* (Stimpson), *Parapenaeus constrictus* (Stimpson), *Hippolysmata wurdemanni* (Gibbes), *Crago packardi* (Kingsley), *Hippolyte pleuracantha* (Stimpson). Porcellanids: *Euceramus praelongus* Stimpson. Thalassinids: *Callianassa stimpsoni* Smith, *Upogebia affinis* (Say). Hermit Crabs: *Pagurus pollicaris* Say, *Clibanarius vittatus* (Bosc.). Crabs: *Ovilipes ocellatus* (Herbst), *Portunus gibbesii* (Stimp.), *Arenaeus cribrarius* (Lamk.), *Cancer irroratus* Say, *Neopanope texana sayi* (Smith), *Panopeus herbstii* Edw., *Pinnotheres maculatus* Say, *Pinnotheres ostreum* Say, *Pinnixia cylindrica* (Say), *Pinnixia chaetopterana* Stimpson, *Ocypoda albicans* Bosc., *Uca pugilator* (Bosc.), *Uca pugnax* (Smith), *Libinia emarginata* Leach, and *Pelia mutica* (Gibbes).

Upper and lower bay.—Shrimps: *Palaemonetes carolinus* Stimpson, *P. vulgaris* (Say), *Crago septemspinosus* (Say). Hermit Crabs: *Pagurus longicarpus* Say. Crabs: *Callinectes sapidus* Rathbun, *Hexapanopeus angustifrons* (Benedict and Rathbun), *Rithropanopeus harrisii* (Gould), *Eurypanopus depressus* (Smith), *Sesarma* (*Holometopus*) *cinereum* (Bos.), *Uca minax* (LeConte), and *Libinia dubia* M. Edw.

The lists just given include those species which were found in the bay, while the list which follows contains the species which have been collected outside, not far from the mouth of the bay.

Outside only.—Shrimps: *Pandalus leptocerus* Smith, *Caridion gordoni* (Bate), *Hippolyte acuminata* Dana, *Latreutes fucorum* (Fabr.), *Spirontocaris pusiola* (Krøyer), *Spriontocaris polaris* (Sabine), *Palaemon tenuicornis* Say, *Pontophilus brevirostris* Smith. Galatheids: *Munida iris* A. M. Edw. Hermit Crabs: *Catapagurus gracilis* Smith, *C. sharreri* M. Edw., *Pagurus acadianus* Benedict, *P. kroyeri* (Stimp.), *P. politus* (Smith). Hippas: *Emerita talpoidia* (Say). Crabs: *Homolo barbata* (Fabr.), *Bathynectes superba* Costa, *Portunus (achelous) spinimanus* (Latr.), *Portunus sayi* (Gibbes), *Cancer borealis* Stimp., *Sesarma (Sesarma) reticulatum* (Say), *Collodes robustus* Smith, *Euprognatha rastellifera aclita* A. M. E. (probably), *E. rastellifera marthae* Rathbun, *Hyas coarctatus* Leach.

A few specimens were collected both outside and in the lower bay.

Outside and lower bay.—Shrimps: *Penaeus setifera* (L.), *P. brasiliensis* (Latr.), *Parapenaeus constrictus* (St.), *Crago septemspinosus* (Say). Hermit Crabs: *Pagurus longicarpus* Say, *Pagurus pollicaris* Say. Crabs: *Ovalipes ocellatus* (Herbst), *Cancer irroratus* Say, *Neopanope texana sayi* (Smith), *Panopeus herbstii* Edw. (probably), *Sesarma (Holometopus) cinereum* (Bosc.), *Ocypoda albicans* Bosc., *Uca pugilator* (Bosc.), *Uca pugnax* (Smith), and *Libinia emarginata* Leach.

The localities for two species, *Hepatus epheliticus* (L.) and *Callinectes ornatus* Ordway, have not been determined.

A study of the lists just given shows that only 1 species was found exclusively in the upper bay (its distribution may be more extensive); that 11 were common to both the upper and lower bay; that 27 were found exclusively in the lower bay; that 25 were taken only outside of the bay; and that the localities of 2 were not determined. This makes a total of 66 species.

The lists below are designed to show the probable distribution of the decapods (for which we have sufficient data) in the offshore waters of Chesapeake Bay; that is, exclusive of the shallow water shore forms and the forms in rivers and creeks. The conclusions arrived at are based on our systematic collections during cruises covering a considerable period, checked to some extent by data from shore, river, and creek collections which, however, have been of an unsystematic nature.

Our data do not afford evidence to show that there are any species of decapods which are distributed exclusively in the offshore waters of the upper bay; that is, above the mouth of the Potomac River.

Decapods of the offshore waters of upper and lower bay.—*Palaemonetes carolinus* Stimpson, *P. vulgaris* (Say), *Crago septemspinosus* (Say), *Pagurus longicarpus* Say, *Callinectes sapidus* Rathbun, *Rithropanopeus harrisii* (Gould), *Eurypanopeus depressus* (Smith), *Hexapanopeus angustifrons* (Benedict and Rathbun), and *Sesarma (Holometopus) cinereum* (Bosc.).

Decapods of the offshore waters of lower bay only.—*Peneus setifera* (L), *Trachypeneus constrictus* (Stimpson), *Crago packardi* (Kingsley), *Euceramus praelongus* Stimpson, *Pagurus pollicaris* Say, *Ovalipes ocellatus* (Herbst), *Portunus gibbesii* (Stimp.), *Cancer irroratus* Say, *Neopanope texana sayi* (Smith), *Panopeus herbstii* Edw., and *Libinia emarginata* Leach.

Almost all of the 18 species of shrimps or shrimplike forms found in Chesapeake Bay and the immediate vicinity have been found in such small numbers that no more information concerning them can be given than that which appears above. Three species, however, *Palaemonetes carolinus*, *Palaemonetes vulgaris*, and *Crago septemspinosus*, deserve more attention, since they have been collected more often in Chesapeake Bay and since we have more data concerning the environmental conditions under which they live.

Palaemonetes carolinus, which is known to occur all along the eastern coast of the United States (Kingsley, 1899), seems to be a shallow-water form, judging from the data at hand and one which is more often taken along the region near the tide lines. It has been caught very seldom on our cruises, probably because these cruises were confined to the offshore waters.

Three specimens only were taken—one at area *Z* in December, 1915 (depth, 17 meters), another at area *I* in January, 1921 (depth, 12 meters; salinity 13.19 per mille at bottom; temperature, 3.4° C. at bottom), and a third at area *V* in March, 1921 (depth, 14 meters; salinity, 11.32 per mille at bottom; temperature, 9.6° C. at bottom). All of these specimens were captured on the winter and spring cruises and none on the summer cruises. The same condition, we shall see, holds true for *Palaemonetes vulgaris*, another shore form, but not for *Crago septemspinosus*, which frequents deeper water. The United States National Museum has another lot of *P. carolinus* consisting of a rather large number of specimens (over 289) evidently collected near the shore by collectors not connected with our survey. All of these specimens with the exception of two were taken during the summer months, and it might be inferred that in the winter this species migrates into deeper water, but the absence from the lot just mentioned of any specimens collected during the winter time may be due to the fact that ordinarily collectors do not go on trips at that time of the year. While the capture of some specimens of *P. carolinus* during our winter and spring cruises and our failure to find any specimens on the summer and fall cruises favors the plausible assumption that there is migration of this form from the shallow, cold water to the deeper, warm water during the colder months and vice versa with the approach of the warmer season, there is still insufficient evidence to establish it as a fact.

It is clear from data collected by the United States National Museum that *Palaemonetes carolinus* is found ordinarily in shallow water and that it flourishes in water of very low salinity. Specimens have been collected at various places along the western shore of Chesapeake Bay in Maryland and also well up in the rivers—for example, at St. George Island, Lower Machodoc Creek, and Blakistone Island, which are, respectively, 10, 20, and 25 miles up the Potomac River. Collections have been made also at Island Creek, which is 12 miles up the Patuxent River.

Undoubtedly this species may be found along the shores and in the rivers of the eastern shore of Chesapeake Bay, although none has been recorded from that region. It has been collected, however, at Smiths Island, Northampton County, Va., probably close to shore, just outside of the mouth of the bay, and there is good reason to believe that it will be found close to shore and in the rivers of the lower part of the bay.

Little is known of the breeding habits of *Palaemonetes carolinus* except that 12 ovigerous specimens were collected 20 miles up the Potomac River, in Lower Machodoc Creek, during July, 1919. Evidently, then, this species, like many others, breeds during the summer.

Palaemonetes vulgaris, the commmon shrimp or prawn, occurs along the whole eastern coast of the United States but is especially abundant in bays and estuaries (Say, 1817). Like *P. carolinus*, it was taken infrequently on our cruises but somewhat more often than that species. All of the adult specimens were caught at areas located in the region between the mouth of the Potomac River and the mouth of the bay. However, the United States National Museum has specimens in their collection which have been found in various places all over the bay from the region of Love Point to Cape Charles City, but practically all of these specimens were collected in shallow water near the shore. Neither our records nor those of the National Museum show that *P. vulgaris* makes its way far into the rivers.

As in the case of *Palaemonetes carolinus,* there are indications that *P. vulgaris* migrates into deeper water during the colder months; for all the specimens, with the exception of two, collected during our cruises were taken during the colder months.

The two exceptions were ovigerous and were found at the shallow area *O* (8 meters) during the July cruise, 1920. The occurrence of these egg-bearing specimens in July and the finding of the larvæ of this form only during the July and August cruises of 1920 show that the breeding season was during the summer months. On those two cruises the larvæ were found at areas covering practically the whole bay (*U, V, W, O, A, D, H′*, and *R′*).

Crago septemspinosus, which has been known under the names *Crangon septemspinosus* Say and *C. vulgaris* Smith, was by far the most common shrimp in our collections during the years 1915, 1916, 1920, 1921, and 1922. It is known to frequent deeper water than *Palaemonetes vulgaris* (Verrill, 1874, p. 45) and is called the "sand" or "grey shrimp" because it is common on sandy bottoms. In the Chesapeake it was collected from all the areas visited with the exception of *U*, which is not far from Baltimore. Probably it is more abundant in the lower two-thirds of the bay, although like *P. carolinus* it has been found at St. George Island and Blakistone Island 10 and 25 miles, respectively, up the Potomac River, and in Island Creek, which is about 10 miles upstream from the mouth of the Choptank River.

Ovigerous specimens of *Crago septemspinosus* were taken at all seasons of the year; but they were caught most abundantly during the fall, winter, and spring cruises. The summer cruises brought to light few ovigerous specimens. Juvenile individuals were reported by Schmitt from our July, August, October, December, 1920, and our March, 1921, cruises. At Woods Hole, Mass., Bumpus (1898) found Crangon breeding during March, and Thompson (1899) during September, while Fish (1925, p. 156) reports "great numbers of adult females bearing eggs in Naragansett Bay" in the month of May, 1922. Bumpus' statement that "* * * it would be interesting to learn when this species is not pregnant," is well put.

Peneus setifera and *P. brasiliensis*, the two large shrimps of markets, have been collected from the lower bay and from such rivers as the Rappahannock, but in small numbers. Evidently they are more at home farther south along the coast.

All the rest of the shrimps collected were found outside only or, in a few cases, in the lower part of the bay and in small numbers. The localities where they have been taken are indicated in the lists given above. Three species, *Hippolyte acuminata*, *Latrutes fucorum*, and *Palaemon tenuicornis*, were collected at the surface only.

The Galatheidea are represented in our collection by the single species *Munida iris* A. M. Edw. Over 1,400 specimens have been collected off Chesapeake Bay by various collectors and placed in the United States National Museum. The records show that these were taken at depths varying from 78 to 328 meters. Evidently it is a form of the deeper and more saline waters. It was never taken inside of the bay during our cruises; but in August, 1920, when we visited several stations located along a line extending from the mouth out to the 100-fathom line, 5 specimens were collected—2 probably at 78 meters and 3 probably at 216 meters (I say "probably" because a nonclosing net was used.) The surface and bottom salinities at the 78-meter station, which was only a short distance from the mouth, were 29.91 and 33.29 per mille. The temperatures were 24.1° C. and 8.5° C. This species must be very abundant in places, for as many as 250 specimens have been collected at a single dredging station.

A rare species of the family Porcellanidæ, namely, *Euceramus praelongus* Stimpson, was collected on three occasions: During October, 1915, off the Inner Middle

Ground between Cape Charles and Cape Charles City; during December, 1915, at area *L*, a little above the mouth of the Potomac River; and during July, 1916, at area *G* in the mouth of the bay. This species which is known to occur along the coast of Carolina and Florida was found in waters of low salinity such as those of the region of the mouth of the Potomac River and also of localities where the salinity was fairly high, as at area *G* (surface 24.90, bottom 31.64 per mille).

Two burrowing forms, *Callianassa stimpsoni* Smith and *Upogebia affinis* (Say), were collected, the first at areas *F* and *B* and the last at area *G*. None were found above the extreme lower part of the bay and none where the bottom salinity was less than 22.69 per mille. All were taken with a commercial dredge known as the "orange-peel bucket," which penetrates to a considerable depth. Other specimens have been found along the shores of Virginia, according to the records of the United States National Museum.

All but three of the eight species of hermit crabs in the collection have been dredged outside of the bay only, in rather deep water off the coasts of Maryland and Virginia. Two of the three species, *Pagurus longicarpus* Say and *P. pollicaris* Say, have been found commonly in the lower bay and outside. The other species, *Clibanarius vittatus* (Bosc), which is known to occur along the coast from North Carolina southward, was not collected on our cruises and is represented in the National Museum only by two specimens, both from Gunston, Va., far up in the Potomac River.

Pagurus longicarpus was collected from the following areas: *E, F, G, A, D, O, J, I*, and *R*. With the exception of three specimens collected at *R* and in the immediate vicinity of that area, all of the 170 specimens were taken below the mouth of the Potomac River. This form was found living in water the salinity of which varied from 30.60 to 17.95 per mille, and the data show that it has been collected during every season and during practically every month of the year. Not much can be said of its breeding habits, but an ovigerous female was collected in October, 1915, off York Spit Light, in about the middle of the bay.

Pagurus pollicaris, the so-called "warty hermit crab," seems to have its distribution in the offshore waters of Chesapeake Bay limited to the southernmost part. It was taken some twenty different times during our cruises but only at areas *G′*, *E, G, F, A*, and *D*, or localities in the near vicinity of those areas. It has been found at all seasons of the year (January, March, April, June, July, October, December), and the occurrence of ovigerous females during the month of April indicates a spring breeding season. Specimens have been found living in water the salinity of which ranged from 18.91 to 30.96 per mille.

No hippas were collected during our cruises. This little crustacean is usually found burrowing in sandy beaches or the shallow waters of sand flats. While our failure to get any specimens does not necessarily indicate its absence from Chesapeake Bay, the records of the National Museum support such a conclusion, since they do not show that it has been collected along the shores of the bay. However, outside of the bay at Virginia Beach, Va., specimens of the hippa, *Emerita talpoida* (Say), have been collected, and they are now in the Museum's collection.

The best known, if not the most common, crab that is found in Chesapeake Bay is the "edible crab" or "blue crab," *Callinectes sapidus* Rathbun, which is found along almost the whole Atlantic coast of the United States. It frequents especially the muddy bottoms of bays and estuaries. This crab was taken infrequently in our offshore dredging and trawling in Chesapeake Bay, and most of the specimens which were captured were juveniles. However, on one occasion, a large catch of

Callinectes was made by us with the beam trawl. This occurred at area *G′*, off Old Point Comfort, where the depth measures about 28 meters. It was during the December, 1920, cruise that the specimens were caught when the bottom water temperature was 10.1° C. The collection consisted of 32 female and 15 male specimens, mostly of large size. All of them were inactive, owing, no doubt, to the low temperature of the water (Churchill, 1919). In the same haul of the beam trawl, which as usual lasted for 10 minutes, 11 flounders and 26 croakers were captured.

Since Callinectes is known to occur all over the bay and even well up into the rivers, it must be capable of living in waters of a great range of salinities.

The "mud crab" *Neopanope texana sayi* (Smith) has been taken in larger numbers on our cruises than any crab found in the bay, but none have been collected north of the mouth of the Potomac River. The specimens of this species which have been deposited in the United States National Museum by other collectors came from the lower bay, judging from the data where the localities are known definitely. Our specimens have been found at areas *A*, *B*, *C*, *D*, *F*, *G*, *G′*, *I*, *J*, *K*, *O*, and *Q*. No specimens have been reported from the Potomac River, even at area *M*, *N*, and *N′* in its mouth. The records of others show that this species is distributed from Provincetown, Mass., southward and that it frequents muddy bottoms in bays and sounds. The character of the bottom, the large numbers of specimens collected, the occurence of ovigerous females and juvenile forms indicate that Chesapeake Bay is an ideal locality for this mud crab.

Specimens have been found at all seasons of the year and during the July, 1920, cruise ovigerous females have been captured. Undoubtedly summer is the breeding season. During the cruises of the fall, winter, and spring, juveniles, probably developing from eggs of the previous summer, have been collected; but on the summer cruises according to our records they have not been found.

The salinity and temperature records show that for 26 hauls the bottom salinity ranged from 14.79 to 31.62 per mille and the bottom temperature from 4.2° C. to 25.2° C.

Rithropanopeus harrisii (Gould), which may be included under the "mud crabs" and which was formerly classed under the genus *Panopeus*, was caught but once during the survey's cruises—namely, at the mouth of the Eastern Bay, where the depth was 37 meters and the bottom was soft, black mud. Undoubtedly, the occurrence under such conditions was unusual. It has been collected frequently along the shores of Chesapeake Bay, both in the upper and lower regions, and often in creeks and rivers. Rathbun (1905) reports it from near the high-water mark under stones and Gould (Rathbun, 1905), has found it in Cambridge marshes and clinging to floating seaweed in the Charles River. The most abundant catches from Chesapeake Bay deposited in the United States National Museum have come from tributary creeks and rivers.

Specimens have been collected during all seasons of the year. Ovigerous ones have been found in June and September and juvenile forms in June, July, August, and September.

Eurypanopeus depressus (Smith), another "mud crab," apparently lives out farther from the shore, for it was taken in regions where the depth of water ranged from 11 to 48 meters. Specimens were captured at areas *K*, *P*, and *I*. Others were found near area *R* and off the mouth of the Potomac River. Females bearing eggs were captured in April and juvenile forms in April, October, and December.

Hexapanopeus angustifrons (Benedict and Rathbun) is another common "mud crab" in the offshore waters of Chesapeake Bay. It has been taken from regions where the depth ranges from 8 to 48 meters. The indications are that it is not a shore form, for the records of the United States National Museum do not include any specimens found on shore collecting trips. Rathbun (1905) speaks of its being found on oyster grounds in Connecticut, and the same is undoubtedly true in the Chesapeake. It was brought up quite often from regions of shelly bottom during our cruises. Forty hauls of dredges, nets, and trawls brought to light over 100 specimens of this crab during the 1915, 1916, and 1920 cruises. They were taken at areas *G*, *G'*, *A*, *C*, *D*, *E*, *H*, *J*, *K*, *L*, *R*, and *S* (close). None was caught farther up the bay than the region of area *S*, which is along the line between Governors Run and James Island.

We have no records of any being taken in rivers or creeks, but it is possible that they may be found there, in the deeper waters especially, where there are oyster bars.

Hexapanopeus has been found in the bay during all seasons of the year. The water in which specimens were caught varied in temperature from about 4° C. to about 25° C. The range of bottom salinities was from about 18.00 to almost 32.00 per mille. These figures are based on 19 hauls and 50 specimens.

Little is known concerning the breeding habits of this species, but the collection contains one ovigerous specimen caught at area *E* in July, 1920, and several juvenile forms taken during the cruises of October, December, 1915, and April, 1916.

The Pinnotheridae, which includes those small forms which live commensally with various invertebrate animals, are well represented in Chesapeake Bay. Since it was not feasible to make any special effort to collect these interesting little crabs, the number of specimens is very small. *Pinnotheres maculatus* Say, the "mussel crab" (Rathbun, 1905) has been collected on two occasions, once off the mouth of the Potomac River and once at area *D*. The female is known to live in the gill cavity of the mussel, *Mytilus edulis*, and the male to lead a free-swimming existence. Also, the female is known to frequent *Pecten tenuicostatus*.

Pinnotheres ostreum (Say), which has similar habits to those of *P. maculatus* except that it is a commensal in the oyster, probably is distributed over all those parts of the bay where oysters are found. However, none was collected on our cruises, and only a few specimens from Chesapeake Bay are in the United States National Museum. Most of these came from the southern part of the bay.

Pinnixa cylindrica (Say), *P. sayana* Stimp., and *P. chaetopterana* Stimp., which are commensals of certain tubiculous annelids, were caught very seldom. *P. cylindrica* was captured once at area *L*, near the mouth of the Potomac River, in about 37 meters of water; *P. sayana* was found near the mouth of the Patuxent River—that is, at area *R* and at a locality near that area where the water was 48 and 7 meters deep, respectively; finally, *P. chaetopterana* was taken in 16 meters of water at area *F*, which is in the mouth of the bay. One haul of the "orange-peel bucket" in the latter case brought up 5 males and 6 females.

Two species of the genus Sesarma, *Sesarma cinereum* (Bosc) and *S. reticulatum* (Say), coming from Chesapeake Bay and vicinity, are in the collection of the United States National Museum. Neither of these has been collected on our cruises, which is not surprising, for they are shore or shallow-water forms. *S. cinereum*, called the "wood crab" and occurring "under logs and drift and about wharves, wooden piles, etc." (Rathbun, 1900, p. 583), has been collected from several localities in the bay: Near Thomas Point (between areas *V* and *Z*); Island Creek in the mouth of the

Choptank River; Mobjack Bay; Hampton, Va.; and Lynnhaven Inlet near the mouth of Chesapeake Bay. In addition it has been found on Smiths Island, Northampton County, Va., which is just outside of the bay. Evidently this form, which, it may be mentioned, has a known distribution from Cape Cod to Florida and along the shores of the Gulf of Mexico, is a shallow-water form.

It has been collected in Chesapeake Bay during the months of June, July, August, September, and December. Undoubtedly, it may be found there at other times. Females carrying eggs have been found during the month of July.

Sesarma reticulatum (Say), which lives in burrows on salt marshes (Rathbun, 1905, p. 4) and which seems to be a better-known form than the previous species, has not been reported from Chesapeake Bay up to the present time, although it seems probable that it will be. However, one specimen has been taken just outside of the bay at Smiths Island, Va.

Ocypoda albicans Bosc., commonly known as the sand crab or ghost crab of sandy shores, has made its way into the extreme southern part of the bay, and has been caught by those collecting for the United States National Museum, at Buckroe Beach, Willoughby Point, Wallops Island, and near Fort Monroe, Va. That region is probably near the northern limit for full-grown specimens of Ocypoda. Only the young have been found in New England, according to Rathbun (1905). Undoubtedly *Ocypoda albicans* is a creature of the sandy shores of the open seas where the winters are mild. The observations of others indicate that Ocypoda is not well fitted to withstand freezing temperatures, so it seems probable that the low-winter temperature of the north is the important factor in limiting its northern range.

Specimens have been collected in the lower bay and in the close vicinity of its mouth during the months of May, August, and September. However, more systematic collecting may show its presence there in the winter time.

So far as the records show, none of the 57 adult specimens collected from the bay and the immediate vicinity was ovigerous.

The fiddler crabs are represented by three species in Chesapeake Bay: *Uca minax* (LeConte), *U. pugilator* (Bosc.), and *U. pugnax* (Smith). These shore crabs have a known distribution from Cape Cod to Florida and then along the shores of the Gulf of Mexico. *Uca minax*, which has been found in salt marshes and also in regions where the water is nearly fresh (Rathbun, 1905, p. 2), has been collected farther up in Chesapeake Bay than any of the other species. Specimens have been caught at Chesapeake Beach, Md., which is about as far up the bay as the line made by areas *V*, *W*, and *X*. Other specimens have been found along Mobjack Bay, Buckroe Beach, and Lynnhaven Inlet, all of which localities are in the southern part of the bay. None is recorded as from outside of the bay. Further investigation, probably, will show that it has made its way up the shores of the rivers. One ovigerous specimen was found during the month of July.

The other two species of fiddler crabs, *Uca pugnax* and *U. pugilator*, have been collected in the lower part of the bay and outside only. An ovigerous specimen of *U. pugilator* was found during the month of July. The known distribution of these forms outside of Chesapeake Bay is the same as that for *U. minax* (Rathbun, 1900).

Six species and one subspecies of spider crabs are listed from Chesapeake Bay and the immediate vicinity. Four of these—*Collodes robustus* Smith, *Euprognatha rastellifera acuta* A. M. E. (probably), *Euprognatha rastellifera marthae* Rathbun, and *Hyas coarctatus* Leach—are deep-water forms which have been dredged near the mouth in the open ocean.

Collodes robustus Smith was dredged in water from 102 to 328 meters, but in other regions it has been found at from 90 to 683 meters (Rathbun, 1925, p. 119). Its known distribution is from Massachusetts to North Carolina, and it has been found during all seasons of the year. Ovigerous specimens have been caught off Virginia in March and off Massachusetts in August and September.

Rathbun's subspecies marthæ of *Euprognatha rastellifera* A. M. E. has been dredged off Chesapeake Bay in water varying in depth from 105 to 306 meters, but farther north it has been found in water from 81 to 419 meters deep. It has been collected at all seasons of the year, but only one specimen, according to the records published by Rathbun (1925, p. 98), was found with eggs. This individual was collected in July off Marthas Vineyard in exceptionally shallow water (81 meters) for that species.

Euprognatha rastellifera acuta A. M. E., which is the more southern subspecies (Habana, Porto Rico) but which has been found as far north as near Marthas Vineyard, is probably represented in our collection by one juvenile specimen. This was taken off the mouth of the bay in 102 meters of water.

Hyas coarctatus Leach, which is commonly called the toad crab, has been dredged along the Atlantic coast of North America from Newfoundland to North Carolina. The records of Rathbun (1925, p. 260) show that it occurs in water ranging from 9 to about 350 meters. It has not been found in the bay, but a few specimens have been taken off of the coast of Virginia.

The so-called common spider crab, *Libinia emarginata* Leach, occurs in Chesapeake Bay, but it has been brought to light only by dredging in water ranging from 7 to 46 meters. All of the specimens collected were from the extreme southern part of the bay where the salinities near the bottom ran from about 21.00 to 31.00 per mille, and the water temperatures from 8.8° C. to 21.9° C. It was caught several times at areas *G*, *G′*, and *A*. A few specimens have been found also in Hampton Roads and off the Inner Middle Ground. There is one specimen in the Chesapeake collection of the United States National Museum which came from outside of the bay, off Virginia Beach. *Libinia emarginata* has been dredged during all seasons of the year, but the records show no ovigerous individuals. Most of the specimens are in the juvenile condition. Rathbun (1925, pp. 311–313, pp. 314–317) records its distribution along the Atlantic coast of North America from Nova Scotia to West Florida, and she finds it occurring on all sorts of bottoms in comparatively shallow water.

Another spider crab, *Libinia dubia* M. Edw., is much more widely distributed over Chesapeake Bay than the former species, and apparently in some localities at least it lives in shallower water (Rathbun, 1925, p. 318). It has been collected at areas *A*, *D*, *E*, *H*, and *Y*, the latter area being off Love Point, not far from Baltimore. In addition it has been taken in the following localities: Hampton Roads, Norfolk, Chincoteague, Tangier in Virginia, and off the mouth of the Rappahannock River, off York Spit, Thomas Point, and Tilghman Island. Apparently *L. dubia* is more at home in Chesapeake Bay than any other spider crab, but we have no records of its occurrence in the rivers. Possibly the lack of specimens from such localities is due to the fact that very little dredging has been undertaken in the rivers, although we are not accustomed to think of spider crabs as frequenting water of very low salinity. While *L. dubia* is known to range along the Atlantic coast from Cape Cod down into the Gulf of Mexico, no specimens have been reported outside, in the region of Chesapeake Bay. Undoubtedly this form may live in water of low salinity, for it has been found as far north as *Y*, where the salinity at the bottom is often not more than 16.00 to 17.00 per mille. Nearly all of the 29 specimens constituting the Chesapeake collection in the National Museum are juvenile forms, as in the case of *L. marginata.* No ovigerous specimens were collected. The records show that specimens of *L. dubia* have been found in the bay at all seasons of the year. We have temperature records taken near the bottom for the areas at which this form was collected. They range from 7.9° C. to 24.4° C.

Finally, there is the spider crab, *Pelia mutica* (Gibbes), which has been collected along the Eastern Shore in Tangier Sound and a few other localities. Specimens of this form were collected by U. S. S. *Fish Hawk* in June, 1891, but none has been taken on the Chesapeake survey cruises during 1915, 1916, 1920, 1921, and 1922. It should be mentioned, however, that Tangier Sound was not visited at regular intervals during these cruises. *P. mutica* is known to frequent bays and sounds. (Rathbun, 1925, p. 279.)

It is clear that some of the crustacea collected from Chesapeake Bay and vicinity have been found exclusively outside of the bay, where the salinity is high, that some have been found exclusively in the bay, where the salinity is much lower. But our data show that others occur in both regions, even though the range of salinities is very great. Furthermore, there is good reason for believing that some crustacea migrate from one end of the bay to the other at certain times of the year. So it seems probable that some crustacea can survive a great range of salinities, at least if the changes take place gradually. Fredericq (1898, p. 831) has been able to increase or diminish to a large extent the salts in the blood of the crab, *Carcinus maenas*, by placing the specimen successively in water of greater or less salinity. Also, he (1889) finds that the blood of *C. maenas* varies with the degree of salinity of the water in which the animal is living. The investigations of other workers such as Issel on copepods, Herdman on copepods, Schmankewitsch on *Artemia salina* (see Flattely and Walton, 1922), and Loeb (1903) on Gammarus show that these forms are able to stand a wide range of salinities. More recently Adolph (1925) has found that a marine species of Gammarus "will live indefinitely if transferred to sea water diluted with distilled water up to 0.5 per cent (0.005 M), or concentrated by the addition of salts up to 160 per cent (1.56 M, corrected for ionization)."

Why some forms have been found only in the lower part of the bay or outside, or in both regions and not in the upper part of the bay, are questions which can not be answered without a careful study of the habits and physiology of individuals of each species in as many of the environments to which they may be subjected in nature.

ARACHNOIDEA

The Xiphosura or horseshoe crabs are represented in Chesapeake Bay by one species, the common *Limulus polyphemus* (L), which was taken in the beam trawl on several occasions. It was found in September, 1916, at area *A*; in January and December, 1920, at *G′*; and in May, 1920, at *F* and *E*. Only eight specimens were captured, all of which, as may be seen from the areas listed, came from near the mouth of the bay. The bottom salinities and temperatures for these areas (area *G′* during the December cruise excepted) ranged from 22.60 to 29.22 per mille and from 2.7° C. to 23.4° C., respectively. The records indicate that *L. polyphemus* may be found throughout the year in the bay, but only in its lowermost portion.

At least one species of the order Pycnogonida has been found by us in Chesapeake Bay. It has been identified, tentatively, by the United States National Museum as *Anoplodactylus lentus* Wilson. It was collected at area *G* in the mouth of the bay during the May, 1920, cruise. The bottom salinity at this area was 25.77 per mille and the temperature 13.8° C.

MOLLUSCA

The rather large number of mollusca which have been collected by us are now in the hands of the United States National Museum, awaiting identification.

ECHINODERMATA

The echinoderms collected during the Chesapeake survey have been identified by Dr. Hubert Lyman Clark, to whom I am much indebted for a list of the species and additional information concerning their geographical distribution.

The number of species is small, but no smaller than might be expected from a rather fresh estuary with a muddy bottom. All of the specimens collected, with one exception, were found either in that part of Chesapeake Bay below the mouth of the Potomac River (most of these were taken not far from the mouth of the bay) or just outside of the bay a short distance.

A list of the species follows: *Asterias forbesi* (Desor), *Stephanaster gracilis* (Perrier), *Echinarachnius parma* (Lam'k), *Amphiodia sp.*, *Amphipholis squamata* (Delle Chiaje), and *Amphioplus abdita* (Verrill). In addition to these echinoderms, which were identified by Clark, a few specimens of the holothurian, *Thyone briareus* (Lesueur), the common red sea urchin *Arbacia punctulata* (Lam'k), and the starfish *Luidia clathrara* (Say) have been found.

The echinoderm, which was captured by far the largest number of times in Chesapeake Bay during the cruises of 1916, 1920, 1921, and 1922, was the common starfish *Asterias forbesi*, which was brought to the surface on 54 occasions. It was collected during the following cruises: April, June, July, September, 1916; January, March, May, July, December, 1920; January, March–April, May–June, 1921; and January, March, 1922. Undoubtedly it may be found in the bay any time during the year but ordinarily only in the region below the Maryland and Virginia line. It has been taken at areas *E*, *F*, and *G* in the mouth of the bay, at area *G'* off Old Point Comfort, at various localities between these two regions, at areas *A*, *B*, *C*, and *D*, which mark a line from Cape Charles City to New Point Comfort, and at areas *Q* and *O*. It will be seen that no specimens were collected above the line marked by areas *H*, *H'*, *Q*, and *O*, which runs from the mouth of the Rappahannock River to Sandy Point. Apparently this form can stand a considerable range of salinities and temperatures, for it was found on bottoms where these ranged from somewhat less than 20.00 to 32.00 per mille and 4.2° C. to 24.4° C. Specimens were taken at depths from 8 meters at area *Q* to 46 meters at area *A*. Frequent catches were made at the latter area, and these were in general the largest made in the bay. The Biological Survey of Woods Hole and Vicinity (Sumner, Osburn, and Cole, 1913, pp. 111–112) showed that *A. forbesi* was encountered with the most frequency of any echinoderm in that region and that it together with *Arbacia punctulata* were the ones taken most often in Buzzards Bay. Similarly in Chesapeake Bay *A. forbesi* was the form most frequently encountered.

Judging from our collections, the starfish *Luidia clathrata* seldom enters the bay. Only on two occasions has it been taken—once in January, 1916, at area *H* and once in July, 1916, at area *F*.

At least two species of brittle stars were found in Chesapeake Bay. One, *Amphioplus abditus*, was taken in August, 1920, at areas *G*, *F*, and *E*—that is, in the mouth of the bay at depths from 16 to 24 meters. The bottom salinities at these areas were all above 30.00 per mille and the temperatures ranged from 15.5° C. to 20.9° C. The other species, *Amphiodia sp.*? (probably *atra* Stimpson according to Clark), was found at area *B* during the same cruise at a depth of 13 meters. At this area the bottom salinity was 24.34 per mille and the temperature 25.0° C.

One species of sea urchin, *Arbacia punctulata* was taken on six of the cruises (June–July, 1916, December, 1920, and January, 1921). Without exception they were found in the mouth of the bay and in four out of six cases at area *G* where the bottom salinities and temperatures varied approximately from 29.00 to 32.00 per mille and 5.9° C. to 21.0° C.

The holothurian, *Thyone briareus*, showed a somewhat more extensive distribution in Chesapeake Bay than the rest of the echinoderms. Specimens were found at areas *A*, *B*, *G′*, *G*, and *P* during the cruises of January and May, 1920, May–June, 1921, January and March, 1922. It will be seen that while most of the specimens were taken in the lower part of the bay, one was found a short distance above the mouth of the Potomac River (area *P*). The indications are that this form is able to stand a wide range of salinities and temperatures. Three other echinoderms are listed above as having been captured during our cruises, but all of these were found outside of the bay between the mouth and the 118-fathom line (216 meters). The starfish, *Stephanaster gracilis*, the common sand dollar, *Echinarachnius parma*, and the ophiuroid, *Amphipholis squamata*, were all found on the same cruise, August, 1920, along the 118-fathom line. The latter was also brought up along the 43-fathom (79 meters) and 20-fathom (37 meters) lines during the same cruise.

It is worthy of note that five species of echinoderms, *S. gracilis*, *E. parma*, *Aphipholis squamata*, *Amphioplus abditus*, and *Amphiodia sp.*? were taken during the August, 1920, cruise when a trip to the 118-fathom line was made in addition to usual trips over the bay.

A review of the eight species of echinoderms shows that only two species, *Asterias forbesi* and *Thyone briareus* have been found far inside the mouth of Chesapeake Bay.

Through the courtesy of Dr. Hubert Lyman Clark I have received the following information concerning the distribution of some of the species: Speaking of the starfish, *Stephanaster gracilis*, and the sand dollar, *Echinarachnius parma*, he says of the former, "A West Indian species. Its occurrence in Chesapeake Bay is noteworthy"; and of the latter, "A *northern* species. Its occurrence at the same station with the preceding species is noteworthy." At the time the above was written Doctor Clark had not been informed that the station in question was outside of the mouth of the bay. However, undoubtedly, the occurrence of a West Indian and a northern species at the same station, even outside of the bay, is worthy of note. Concerning the species of Amphiodia he says: "* * * the Amphiodia is perhaps the most important of your captures. If it is *atra*, as seems probable, its type locality is Charleston, S. C."

CHORDATA

HEMICHORDATA

Fragments of a species of Balanoglossus, probably *Dolichoglossus kowalevski* (A. Agassiz), have been brought up by the beam trawl and orange-peel bucket. These came from about 11 meters off Lynnhaven Roads and from somewhat deeper water off the mouth of the Potomac River. The salinities and temperatures at the bottom were 28.30 per mille, 10.9° C., and 18.93 per mille, 2.7° C., respectively. Also specimens of Balanoglossus have been reported from areas *S* and *X* farther up the bay. Balanoglossus undoubtedly occurs in abundance on the sand flats in the southern part of the bay.

UROCHORDATA

The dredging records show that the ascidian, *Molgula manhattensis* (DeKay), was widely distributed over the northern half of the bay. It was taken in largest numbers in the region between the Patapsco River and Kent Island. Only a very few specimens were found below the mouth of the Potomac River, and none, so far as our records show, below the mouth of the Rappahannock River.

CEPHALOCHORDATA

No specimens of Amphioxus have been discovered in our dredgings, but *Branchiostoma virginiæ* Hubbs (formerly known as *B. lanceolatus*) has been found on several occasions by collectors. See Rice (1880), Hubbs (1922), and Hildebrand and Schroeder (1928).

VERTEBRATA

The only vertebrates collected on our cruises were fishes; and these have been reported in another publication by Hildebrand and Schroeder (1928), together with an extensive collection made by them both inshore and in deep water.

CONCLUSIONS

The conclusions arrived at below are based on data resulting from frequent ecological investigations of some thirty areas widely distributed over the offshore waters of Chesapeake Bay. These investigations have been undertaken, usually, during all seasons, often over a period of two or three years and in a quite uniform manner.

1. Chesapeake Bay is a shallow, tidal, slow-moving body of water, averaging, in offshore regions, from 9 to 12 meters (30 to 40 feet) in depth. Water of oceanic salinity (35 per mille) does not enter the bay but large volumes of fresh water are emptied into it by many rivers.

2. A deep-water channel, which lies for the most part nearer the eastern shore of the bay, shows, at intervals, deep-water holes, some of which attain a depth of a little over 47 meters (156 feet).

3. The bottom is largely muddy with few rocky areas; but along the shores, especially in the southern part of the bay, there are sandy regions.

4. While Chesapeake Bay is a tidal body of water, the currents are weak; and there are, ordinarily, no extensive replacements of fresh water by sea water and vice versa during flood tide and ebb tide, respectively. It follows that salinity samples collected from one end of the bay, to the other during a period of four or five days afford a fairly good idea of the salinity conditions for the whole bay during that time.

5. On the other hand, there are regions, such as at the mouths of rivers, at the head of the bay, and at the mouth of the bay, where the salinity may change rather rapidly, especially during periods of river freshets, unusually high tides, and long-continued wind from one direction. Furthermore, the study of deep-water currents shows that, during the autumn and winter, the deep water at times may move continuously, although slowly, into the bay during periods which are considerably longer than those of the ordinary flood tide.

6. The surface salinity records for the mouth of the bay show a variation from approximately 19.00 to 30.00 per mille and for area *U* near the head of the bay from approximately 3.00 to 12.00 per mille. The more saline water was found as a rule along the eastern side.

7. The bottom salinity records for the mouth of the bay show a variation from approximately 26.00 to 32.00 per mille and for area *U*, near the head of the bay, from approximately 6.00 to 17.00 per mille. The more saline bottom water was found on the eastern side of the bay except near the mouth of the Potomac River, where the deep channel approaches the western side.

8. A sharp increase in salinity somewhere between the surface and 20 meters is quite marked in certain regions during the summer and autumn. Such a condition is found especially along the deep-water channel, sometimes at the mouths of rivers, and usually at the mouth of the bay. At times during the winter and spring months this condition is not so evident.

9. Sometimes, especially during the early part of the year, when large quantities of fresh water enter the bay and when there is a greater tendency toward instability, the water approaches a homohaline condition from surface to bottom.

10. While water samples could not be collected simultaneously at the various areas visited during a cruise, the salinity values obtained point strongly toward the conclusion that the salinity of the bay as a whole decreases markedly in the early part of the year, that it increases gradually during the middle of the year, and that it reaches a maximum toward the latter part of the year.

11. The same data, as might be expected, show a decreasing range of salinity values with few exceptions from the mouth to the head for each depth investigated.

12. The surface temperature at the mouth of the bay varies at least from 4° C. to 27° C. (area *G*) and near the head of the bay (area *U*) from 0.0° C. to 25° C. We have not been able to formulate any definite rule for the distribution of surface temperature with reference to the east and west sides of the bay.

13. The bottom temperature at the mouth of the bay varies at least from 3.6° C. to 21.0° C. (area *G*) and near the head from at least 0.9° C. to 24.4° C. (area *U*). During the summer cruises the coldest bottom water was found along the deep-water channel, while during the winter cruises this channel contained the warmest water.

14. A discontinuity in range of temperatures from the surface to the bottom occurs, especially during the warmer months of the year, when the water is more stable. This discontinuity often corresponds closely in depth to that of the discontinuity of the salinity.

15. The temperature data for the winter cruises indicate that there was a decreasing range from the mouth to the head and that this was partly due to the entrance of the warmer water from the ocean; during the spring cruises the temperature data showed that these relations were not constant; during the summer cruises the deep-water temperatures showed an increasing range from the mouth to the head, and this undoubtedly was partly due to the entrance of ocean water, which is of a lower temperature than that of the bay water at this season; finally, the temperatures of the autumnal cruises indicate that, at that time, the summer conditions were changing to those of the winter.

16. Practically all of the marine planktonic diatoms found in Chesapeake Bay during the year 1916 belonged to the neritic temperate group, only one neritic arctic

and no neritic tropical species having been found. The oceanic forms were represented by very few species and small numbers of individuals. One oceanic tropical and two oceanic boreal arctic species were found. Marine bottom or semi-bottom (tycopelagic) diatoms occurred abundantly.

17. While the diatom collections and counts were not made daily in any one locality, the study of large numbers of surface and deep-water samples from regions widely distributed over the bay indicates that during the years of 1916 and 1920 there was a well-marked spring maximum. There are also indications of an autumnal-winter increase after a summer minimum, but the diatom counts are ordinarily not nearly so high as those of the spring cruises. The diatom counts for the summer almost invariably show a marked decrease when compared with those of the spring.

18. Ordinarily, high diatom counts were found at times of low salinity, but it does not follow that low salinity was the cause of the high counts.

19. Total diatom counts at areas in the mouth of the bay, where the depths are shallow and the currents comparatively rapid, were found to be low.

20. Surface and most deep-water samples of the littoral bottom diatom, *Skeletonema costatum*, taken during the cruise of October, 1915, show that the largest counts were near the mouth of the Potomac River. The vertical distribution of this diatom showed the highest counts usually at intermediate depths. The maximal counts were found during the spring cruises.

21. *Paralia sulcata*, a tychopelagic diatom with a heavy test, was also found in largest numbers near the mouth of the Potomac. The bottom samples as compared with surface and intermediate samples contained almost invariably the largest numers of specimens. The maximal counts occurred during the spring cruises.

22. The fresh-water protozoan, Difflugia, which is ordinarily a bottom form, was found widely distributed over the bay during all the cruises in the year 1916. The largest numbers were taken during the July and September cruises.

23. The silicoflagellate, *Dictyocha fibula*, was caught most abundantly in the lower half of the bay. Probably it has an autumnal maximum.

24. The most abundant peridinian listed by Cunningham for Chesapeake Bay was *Ceratium furca.*

25. *Noctiluca miliaris*, one of the cystoflagellates, was found on nearly every cruise during 1915 and 1916, but it was only in the lower end of the bay that individuals of this species were caught in abundance.

26. Comparatively few sponges were dredged in the offshores water of Chesapeake Bay. Undoubtedly this scarcity is due largely to the muddy character of the bottom and to the lack of solid objects for attachment.

27. Large quantities of hydroids belonging to the genus Thuiaria have been found in Chesapeake Bay throughout the year, although the indications are that they are in greater abundance during the spring months. Much of the material collected was loose but not floating at the surface. Three species of this genus are represented, *Thuiaria argentea*, *T. cupressina*, and *T. plumulifera*.

28. The Hydromedusa, *Nemopsis bachei*, was brought in by the townets in greater abundance than any other species in the collections made during 1920 and 1921 (H. B. Bigelow). The records indicate that it is present throughout the year.

29. The jellyfish, *Dactylometra quinquecirrha*, occurs in large numbers in Chesapeake Bay and is usually in the "Chrysaora stage." Records for 1915 and 1916 (Radcliffe) and observations of others support the view that it is abundant in the late

summer and autumn. During the latter season especially it is found well up in the rivers emptying into the bay. Evidently it can stand wide ranges of temperature and salinity.

30. One gorgonian, probably *Leptogorgia virgulata* (Lm'k), has been found at many stations in the lower part of the bay, but since we have never brought it in attached to rocks, stones, or other objects it may have been swept in by the currents from the ocean.

31. Only one species of sea anemone has been taken in the offshore waters of the bay; and, judging from our dredging records, it was confined to the upper half of the bay, showing that it is able to live in water of low salinity.

32. Observations made on the occurrence of ctenophores in Chesapeake Bay support the view that there is a scarcity of full-grown specimens, at least, during the spring months, that the numbers increase in early summer, that they reach a maximum in the late fall, and that during part of the winter they are still present.

33. No live corals were found in the bay.

34. The nematodes are represented by at least a dozen genera and upward of 20 species, according to Cobb.

35. Of the three species of sagittas found in Chesapeake Bay, *Sagitta elegans* was by far the most abundant. There is much evidence which supports the conclusions that this form was scarce in the bay during the July and August cruise, 1920; that during the October and December cruises, 1920, the numbers were larger, although the specimens were young; and that during the late winter cruise, January, 1921, the numbers were large and some of the specimens almost adult. At the time of the March–April cruise, 1921, maximum numbers were caught, many specimens of which were of large size.

36. The largest numbers of *Sagitta elegans* were found near the mouth of the bay during the cruises of July, August, October, December, 1920, and January, 1921; but during the March–April cruise, 1921, large numbers occurred in the extreme upper part of the bay. It is significant that in this same region, at the same time, the largest catches of copepods for all the cruises were made, and that copepods are known to be the food of sagittas.

37. The occurrence of *Sagitta elegans* near the head of the bay during the March–April cruise of 1921 was probably not peculiar to that year, for the log shows that on the March cruises of 1920 and 1922 sagittas were caught in almost exactly the same areas.

38. All our records show that *Sagitta elegans* frequents the layers below the surface during the daytime and that it is able to withstand a large range of salinities.

39. Evidently the presence of solid objects upon which Bryozoa may attach themselves is an important factor determining distribution; but the occurrence of one species only near the mouth of the bay, where the salinity is comparatively high, and another only well inside of the bay, where the salinity is much lower, indicate strongly that salinity is an important factor in distribution (Osburn's view also).

40. Echinoderms are not abundant in Chesapeake Bay, but the common starfish, *Asterias forbesi*, is undoubtedly present throughout the year but only in the region from the mouth of the Potomac River southward. The largest catches were made at area *A*. The salinity and temperature records show that this starfish can live in waters which range from 20.00 to 32.00 per mille and 4.2° C. to 24.4° C.

41. The holothurian, *Thyone briareus*, while not so common in our collections, has a similar distribution to *Asterias forbesi*. Other echinoderms have been taken only near the mouth of the bay and so infrequently that they need no further comment.

42. There are only two abundant annelids, *Nereis limbata* and *Polydora ligni*, which are found widely distributed in the offshore waters of the bay. They have been collected during all seasons of the year. These species and such others as *Goniada oculata*, *Pectiniaria gouldii*, and *Paranaitis speciosa* are evidently able to live in waters of widely differing salinities and temperatures.

43. Four species, *Streblospio benedicti*, *Scolecolepis viridis*, *Prinospio plumosa*, and *Pectinaria gouldii*, have been dredged only from that part of the bay extending from the mouth of the Potomac River to near the mouth of the Patapsco River, and consequently from waters of low salinities.

44. The following were found only in the lower half of Chesapeake Bay, where the salinities are much higher: *Lepidonotus squamatus*, *Harmothoe aculeata*, *Nereis dumerilii*, while *Myriana cirrata*, *Glycera americana*, *Maldane elongata*, *Praxiothea torquata*, *Eupomatus dianthus*, *Terebella ornata*, and *Loimia turgida* were only discovered near the mouth of the bay.

45. While there is no proof from the data at hand that the degree of salinity is a factor governing the distribution of the annelids in Chesapeake Bay, yet there are indications that such is the case. However, it is certainly true that the character of the bottom and the occurrence of the proper kind of food are important factors.

46. One species representing the Hirudinea was found in the offshore waters of the bay. It was the fish-leech, *Piscicola punctata*.

47. Of the 64 species of copepods collected, only two—*Acartia clausii* and *A. longiremis*—have been found sufficiently abundant in the bay to be of economic importance. These were distributed over the whole bay from the region of Baltimore to the mouth and were caught during all the cruises throughout the year. Ten species, including the two mentioned, must have been able to accommodate themselves to a large range of salinities, since they were collected, in good condition, all over the bay, in addition to the ocean. Both of these species have been found breeding in Chesapeake Bay.

48. Two species of barnacles, *Balanus improvisus* and *B. eburneus*, have been collected in the deeper waters of the lower part of Chesapeake Bay (from the mouth of the Potomac River to the mouth of the bay). However, along the shores of the bay there is at least one unidentified species which is found frequently on piles as far north as the mouth of the Patapsco River.

49. The collection of amphipods, consisting of nine species, represents merely the catch made during the cruise of May, 1920. All of the specimens came from the shallower areas and from water that did not exceed 21.00 per mille in salinity.

50. Information concerning the isopods of Chesapeake Bay is limited to material collected on the cruise of May, 1920. Five species were found.

51. The most abundant schizopod caught during our cruises was *Neomysis americana* (formerly known as *Mysis americana*). Large numbers of surface towings show that this species does not ordinarily frequent the surface waters in the daytime. Specimens were captured during all the cruises taken in the year 1920 (January, March, May, July, August, October, and December). Some breeding individuals were found on almost all of the cruises. The records show that this form can live in waters of a wide range of salinities and temperatures.

52. One species of stomatopod, *Chloridella empusa* (called *Squilla empusa* by the earlier systematists), has been caught in the bay. This common, shore-dwelling marine form has been found distributed from near the mouth of the bay to a region

off Bloody Point in waters the salinities of which ranged from about 26.00 to 16.00 per mille.

53. The only cumacean found on our cruises was probably *Oxyurostylis smithi.* Several specimens were captured in May, 1920, off the mouth of the Potomac River.

54. Collections of decapods made in each case in a similar manner, at different seasons during the year, and at widely distributed areas in the offshore waters of the Chesapeake Bay did not bring to light any species confined to the upper half of the bay. On the other hand, a number of species have been found only in the lower part of the bay and outside.

55. Of the 18 species of shrimps or shrimplike forms only *Palaemonetes carolinus, P. vulgaris,* and *Crago septemspinosus* have been found in abundance. *P. carolinus* frequents shallow water along the tide lines and flourishes in water of low salinity. It breeds in the summer time and may be found many miles up rivers where the water is almost fresh. *P. vulgaris,* on the other hand, has not been reported from river waters, although it is found in shallow waters near tide lines. It has a summer breeding season. *C. septemspinosus* frequents the deeper areas of Chesapeake Bay, but it also, like *P. carolinus,* has been found in some of the rivers. Ovigerous specimens have been collected at all seasons.

56. Two species of hermit crabs, *Pagurus longicarpus* and *P. pollicaris,* have been found in considerable numbers. Both were confined almost entirely to the region extending from the mouth of the Potomac River to the mouth of the bay. Specimens were captured in waters ranging from about 18.00 to 31.00 per mille in salinity and were found at all seasons during the year. An ovigerous specimen of the first species has been caught in the autumn, and several ovigerous specimens of the second species have been found in the spring.

57. The common edible crab, *Callinectes sapidus,* which is such a familiar form along the shores of Chesapeake Bay, was taken infrequently in our dredging and trawling. Such specimens as were captured were usually juveniles. But in December, 1920, off Old Point Comfort 32 female and 15 male specimens, mostly of large size, were caught in the trawl. All of these specimens were inactive, owing, no doubt, to the low temperature of the water (10.1° C.). It is well known that Callinectes is distributed all over the bay and well up into the rivers. Evidently individuals of this species can live in waters of wide ranges of temperature and salinity.

58. The "mud crabs" are well represented, four species having been found. Two of these, *Neopanope texana sayi* and *Hexapanopeas angustifrons,* occurred in considerable abundance. The former has been caught only in the southern half of the bay, while the latter has a little wider distribution. Both species are to be found throughout the year, and they breed during the summer. They have been taken from waters of wide ranges of temperature and salinity.

59. Five species of "commensal crabs"—three from the tubes of annelids, one from the oyster, and one from the mussel—have been collected.

60. Spider crabs are classed as marine forms, but three species have been found in Chesapeake Bay. *Libinia dubia* has been taken in many places and as far north as Love Point, near Baltimore. No ovigerous specimens have been found, and nearly all have been in the juvenile condition.

61. The distribution of the crustacea in the bay indicates that there are many forms which can live in waters of a wide range of salinities and temperatures.

62. Horseshoe crabs have been found only at the areas close to the mouth of the bay.

63. Balanoglossus and Amphioxus occur in the lower part of Chesapeake Bay, while the ascidian, *Molgula manhattensis*, has been taken in large numbers from the region between the mouths of the Patapsco and Rappahannock Rivers—in other words, in the less saline part of the bay.

64. The only vertebrates collected on our cruises have been fishes.

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DEVELOPMENT AND LIFE HISTORY OF FOURTEEN TELEOSTEAN FISHES AT BEAUFORT, N. C.[1]

❧

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[1] Submitted for publication, April 8, 1930.

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INTRODUCTION

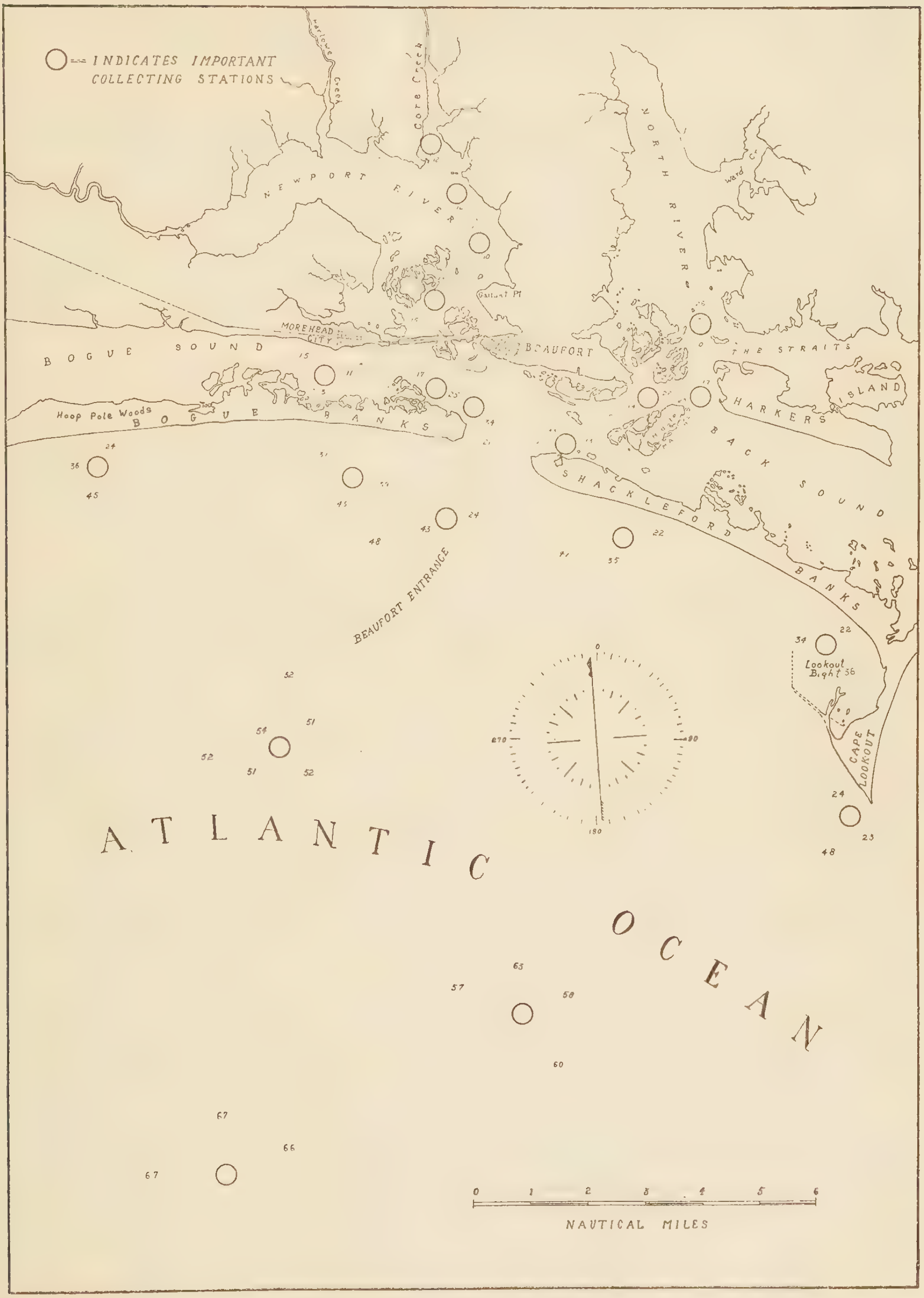
A special study of the development and the growth of teleosts in the vicinity of Beaufort, N. C., was begun in the spring of 1926. This investigation has been continued, as other duties permitted, to the present time (March, 1930). The work was conducted under the direction of the senior author who at first was assisted by Irving L. Towers, formerly junior aquatic biologist, Bureau of Fisheries, and since the summer of 1927 by Louella E. Cable, the junior author. Dr. James S. Gutsell, associate aquatic biologist with the bureau, too, rendered important service, for he did nearly all the offshore collecting, mentioned subsequently, and at times sorted collections and assisted in making measurements and preliminary identifications.

Irving L. Towers served as collector and general assistant during the first year of the investigation. Mr. Towers prepared most of the drawings, illustrating the development of the pigfish and the anchovy, accompanying this paper, and he also made many of the measurements used in the tables. Mr. Towers was succeeded by the junior author who prepared all the drawings, exclusive of those already mentioned. She also assisted in collecting and identifying specimens. She made most of the measurements used in the tables, drew the graphs, and carefully reviewed the manuscript. The senior author is responsible for the final identification of specimens, for any errors that may be included, and the conclusions drawn from the data presented.

In general, only those species for which fairly complete series of specimens showing the development, at least of the young, have been obtained and studied are included in this paper. Many others for which the information is less complete are being held for further study and future report. Although the investigation is to be continued, it nevertheless seems advisable to make available to others the information gained relative to the species included in this paper. The stages in the development of the forms discussed, at any rate, are fairly completely shown. Little or no hope is entertained of soon getting the eggs of the species reported upon in this paper for which they have not already been obtained. It seems quite evident that the eggs either must be sought by a new method of collecting or in areas not yet explored with the apparatus used. On the other hand, eggs have been obtained of a few species not reported in this paper for which all the stages in development either of the egg or the young or both have not yet been found or studied.

METHODS

The collection of specimens and life history data was begun in the spring of 1926, as stated elsewhere, and continued more or less regularly to the present time (March, 1930). Specimens were collected at various places in Beaufort Harbor and its many arms, including two large estuaries and numerous bays, creeks, and ditches. Occasional collecting trips also were made in Bogue and Core Sounds, both connected with Beaufort Harbor. The principal collecting stations are shown on the chart. (Fig. 1.) All of these waters, except for Ocracoke, Beaufort, and Bogue Inlets, are


INDICATES IMPORTANT COLLECTING STATIONS
Harlowe Creek
Core Creek
NEWPORT RIVER
NORTH RIVER
Ward Cr.
Gallant Pt
MOREHEAD CITY
BEAUFORT
THE STRAITS
HARKERS ISLAND
BOGUE SOUND
Hoop Pole Woods
BOGUE BANKS
BACK SOUND
SHACKLEFORD BANKS
BEAUFORT ENTRANCE
Lookout Bight
CAPE LOOKOUT
ATLANTIC OCEAN
0
90
180
270
0 1 2 3 4 5 6
NAUTICAL MILES
24
36
45
15
17
34
17
31
45
48
43
24
22
41
35
34
22
56
52
54
51
52
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60
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66
67

FIGURE 1.—Map of Beaufort Harbor and neighboring waters. Numbers on the map show the depth of the water in feet at the principal collecting stations

inclosed by Bogue and Shackleford Banks, consisting of long, narrow strips of land, usually referred to merely as the "banks." Wherever the designation "banks" is used in the present paper, without further qualification, it refers to Bogue and Shackleford Banks.

During the winter of 1926 and 1927 the collection of specimens off Beaufort Inlet also was undertaken. From that time, until near the end of 1929, offshore collecting trips at weekly intervals, the weather permitting, were made. Although the course was varied from time to time, the most usual one followed extended from Beaufort Inlet to Cape Lookout. From Cape Lookout a west-southwest course was held for 12 to 15 miles, and from thence a due north course was taken until comparatively shallow water was reached off Bogue Banks, about 6 miles west of Beaufort Inlet. Thereafter, the shore of the bank was followed back to Beaufort Inlet. Generally five to seven stations were made during the course of each trip.

During the early months of the investigation eggs and fry were collected with small plankton nets. Other collecting was pursued with an otter trawl and with small collecting seines. A small dragnet about 12 feet long and 3 feet deep, made of bobbinet, was found especially useful for collecting young fish in shallow water from their favorite hiding places in eel grass and other vegetation. This net was very useful also in collecting young fish in small brackish creeks and ditches and was used to good advantage from time to time throughout the investigation.

In January, 1927, 1-meter townets, made of bolting silk with a suitable ring for hauling at the surface and a frame for dragging the bottom, were acquired. This apparatus was used exclusively in the offshore collecting until the autumn of 1929. It was used regularly for a couple of years in the inshore waters also to supplement the collecting done there with other gear.

Meter townets were by far the most useful gear used. They are excellent for collecting the eggs and the fry. However, after the young fish reach a length of about 10 millimeters and more, they are not readily caught in 1-meter townets. Certain species may then be collected in shallow water with a fine-mesh seine, such as is described in a preceding paragraph. Others do not enter shallow water and can be taken only with nets that may be hauled in somewhat deeper water. Because no apparatus suitable for taking the young after considerable growth had been attained, some of our series remained incomplete for a long time. In some cases numerous fry, as well as fish large enough to be caught in ordinary collecting seines and trawls, were at hand, but intermediate sizes were missing.

During the last year of the investigation considerable success in catching intermediate or missing sizes was attained by covering the cod end of an otter trawl with a sack of bobbinet constructed like a 1-meter townet, except that it was found advantageous to make it longer in order to cover more of the trawl. To attach the bobbinet to the trawl, a heavy cord is run through the meshes of the large net, and the smaller net is fastened to the cord with harness snaps or with strings. It was feared that the bobbinet would be torn. This difficulty has seldom been experienced. By placing the bobbinet on the outside instead of the inside of the trawl—another method considered—the small fish are "screened" from the big ones. The catch in the bobbinet may be washed into a container, without hand picking, like a townet collection, preserved, and sorted at leisure in the laboratory.

It will be seen from the frequency tables presented in this paper that fewer measurements generally were made of certain intermediate-sized specimens than of smaller and larger ones of the same year class. The reason is that the method devised for collecting fish of such sizes was used only during the last year of the investigation, whereas methods for taking the small fry and larger young were used much longer. The result is, of course, that fewer specimens of the intermediate sizes generally were obtained.

In addition to the collections made during the present investigation the authors have had for study and comparison certain collections of young fish from the South Atlantic coast of the United States and in the West Indies made by the United States Bureau of Fisheries vessels, the *Fish Hawk*, the *Albatross*, and the *Grampus*.

The discussions, measurements, and drawings of eggs and of the recently hatched young, resulting from these eggs, are based upon living material. In all other instances the data were obtained from preserved specimens. Length measurements of specimens as given in this paper are total lengths; that is, they include the caudal fin or fin fold.

REMARKS

Many species of fishes that are common in the shallow waters during the summer leave these areas in the autumn upon the approach of cold weather. This not only happens at Beaufort, but it takes place in Chesapeake Bay and, no doubt, quite generally along the Atlantic coast of the United States. The following spring the fish return to reoccupy their summer feeding grounds. In most cases it is not known, however, where these fish have their winter homes.

The spot and the croaker—two species subsequently discussed in this paper—are among the species that leave their summer homes in the autumn and, at Beaufort, at least, are seldom seen during the winter. In view of this fact it is especially interesting that their young are exceedingly numerous in the local waters during the winter, and that this season, in fact, is their spawning time. Fry of these species, so small and so young that they certainly are not more than a few days old, occur regularly in abundance along the outer shores of the banks and at sea as far offshore as winter collecting has been extended; that is, about 15 miles. How much farther they occur at sea, of course, remains unknown.

It is pointed out in subsequent sections of this paper that the smallest fry collected—only 2, 3, and 4 millimeters in length—are helpless creatures and certainly unable to swim in any definite direction. This leads to the conclusion that, under the usual weather conditions prevailing at Beaufort, they must have been hatched in the general vicinity where they are taken. If that be true, then it follows that the spawning fish can not be far away. The theory, therefore, is advanced, in subsequent sections of this report that the adult fish, after leaving their summer homes, occupy water not very far from the shores and there perform their reproductive processes.

Some evidence also is produced in that section of this paper dealing with the pigfish indicating that this fish, too, has its winter home only a comparatively short distance from the shores. The writers, accordingly venture to predict that, in time, it will be found that most of the numerous species taken in the shallow shore waters during the summer, constituting in fact the bulk of our food fishes, merely migrate to deeper and warmer water, possibly in the vicinity of the Gulf Stream which flows past Beaufort at a distance of only about 30 miles offshore.

It is very interesting, also, that the young of the scad, *Decapterus punctatus* and of the flyingfishes, *Parexocœtus mesogaster* and *Cypselurus furcatus*—all summer spawners—have been taken in large numbers off Beaufort Inlet, while the adults are known from that vicinity from only a few to several specimens. It is judged from the abundance of the young that the adults too must be common. These species probably escape capture, because they evidently seldom enter shallow water near the shores where they would be caught in fish nets, and being principally pelagic in their habits, efficient apparatus for their capture at sea, at or near the surface, is not available.

ANCHOVIELLA EPSETUS (Bonnaterre) and ANCHOVIELLA MITCHILLI (Cuvier and Valenciennes). Anchovies

Only two species of anchovies, namely, *Anchoviella epsetus* [2] and *A. mitchilli*, are common in the vicinity of Beaufort. Two others, *A. perfasciatus* and *A. argyrophanus*, both generally of more southern distribution, have been recorded from there once. These species were not seen during the present investigation and may be regarded as mere stragglers. The life histories of the two common anchovies of Beaufort are closely related, and it seems advisable to consider them together. They are both of wide distribution; *A. epsetus* ranging from Cape Cod, Mass., to Uruguay and *A. mitchilli* from Cape Cod to Brazil. Locally *A. mitchilli* is much more numerous than its relative.

ECONOMIC IMPORTANCE

So far as known to the writers, anchovies are not used commercially in America, although in Europe they are packed in oil somewhat similar to sardines. *A. epsetus* reaches a maximum length of about 6 inches and a weight of 1 ounce, and an average length of about 4½ inches with a weight of one-half ounce. This size, therefore, apparently is sufficiently large, and if this fish could be obtained regularly and in sufficient quantity over a considerable period of time, it probably could be utilized commercially. This, apparently, is not possible locally, as it is erratic and uncertain in its appearance. *A. mitchilli*, on the other hand, is much more constantly present and much more numerous. Since it seldom reaches a length of 4 inches and its average length is only about 3 inches, its size probably is too small for commercial use.

The economic importance of the local anchovies, therefore, is indirect and probably only as they enter into the food of commercial fishes. In this respect they appear to be very important, for anchovies occur in the stomach contents of local predatory fishes more often than any other fish, with the possible exception of the silversides. The smaller anchovy, *A. mitchilli*, probably because of its greater abundance and more universal local distribution, is by far the more important of the two in this respect. These small fishes quite certainly are of much economic value and their great importance as food for commercial fishes generally is not realized.

SPAWNING

Comparatively little information is obtainable in the literature concerning spawning in the two species of anchovies now under consideration. Kuntz (1914, p. 13) found the eggs of *A. mitchilli* in the tow when he began working at Beaufort on June 9, 1913, and every day until he quit on August 23, and he concludes that the height of the spawning season probably is reached during July. Hildebrand and Schroeder (1928, pp. 110 and 111) state that the spawning seasons of these two species appear to be identical in Chesapeake Bay, and that both extend through May, June, July, and August.

The collection of the eggs and the young at Beaufort during the present investigation appears to show, however, that *A. epsetus* begins spawning earlier than

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[2] This species long was known as *brownii* but this name had to give way to *epsetus*, owing to the law of priority. (Jordan and Seale, 1926, p. 396.)

A. mitchilli, and that it also completes the process considerably earlier. The eggs of *A. epsetus* were taken as early as April 16; they were abundant throughout May, but early in June they diminished in number, although a few were taken throughout July. The eggs of *A. mitchilli* were first taken on April 26, and they occurred in the tow throughout the summer and well into September. Small young only about 12 millimeters long were taken in December, which further indicates that spawning extends well into the autumn.

Both anchovies spawn within the harbor, the estuaries, and sounds, as well as along the outer shores of the banks.

DEVELOPMENT OF EGGS AND YOUNG

The eggs of *A. epsetus* were especially numerous at offshore collecting stations, and it seems probable that this species spawns principally along the outer shores of the banks, although exclusive of 1929, they were common, also within the harbor. The eggs and young of *A. mitchilli* were common wherever towings were made and spawning appears to take place generally in all the local waters.

The eggs, as already indicated, were taken for study with townets. No fish ripe enough for stripping were seen, and they will not stand transportation to the aquarium. The eggs of *A. mitchilli* were known already when this study was undertaken (Kuntz, 1914, p. 14) and the identification of the eggs of *A. epsetus*, therefore, was easy and certain, for anchovy eggs are quite distinctive, and the identification could readily be made through a simple process of elimination. The identification was verified, however, by the examination of eggs secured directly from nearly ripe fish.

Spawning in these species, as in several other local marine forms, appears to take place very definitely early at night; that is, from about 6 to 9 o'clock. At least, no eggs in the early cell-division stages were taken at any other time, although numerous collections were made. Furthermore, eggs taken during the day appeared to be in two fairly uniform stages of development; that is, eggs taken in the tow during the morning, for example, and examined about noon, generally were either in a state of development that showed the embryonic streak or they contained advanced embryos. The eggs with an embryonic streak very probably had been spawned on the previous evening, whereas those containing advanced embryos were spawned 24 hours earlier.

Segmentation and the development of the embryo.—Cell division in *A. epsetus* is regular, and it proceeds rapidly. Unsegmented eggs taken in the plankton between 8 and 9 o'clock in the evening, apparently just laid, passed through the 2 and 4 cell stages and reached the 8-cell stage within an hour at a water temperature near 67° F. Segmentation proceeded rapidly and within 12 hours a definite embryonic streak was formed. Hatching occurred within about 48 hours at a water temperature varying from 66° to 70° F. (Figs. 2, 3, 4, 5, and 6.)

Soon after fertilization a very evident streaming of protoplasm to the upper pole of the egg takes place, forming a pronounced blastodisc. When cleavage takes place, very deep fissures are made and the first cells stand out, mountainlike, on the upper pole of the egg. As cell division proceeds, the fissures naturally become less pronounced and the bell shape of the blastoderm becomes very distinct. Because of the transparency of the egg, the development can be seen clearly.

When the embryonic streak once is formed, the embryo very soon becomes differentiated and development progresses rapidly. (Fig. 7.) Shortly before hatching, the embryo extends nearly around the circumference of the yolk. Heart action may be observed and the embryo is capable of considerable movement. (Fig. 8.)

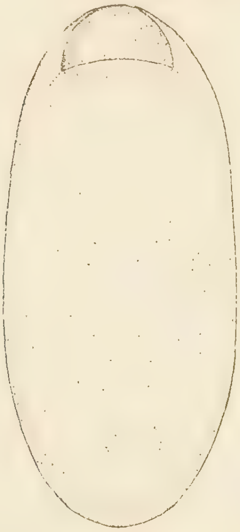

FIGURE 2.—*Anchoviella epsetus.* Egg with fully developed blastodisc

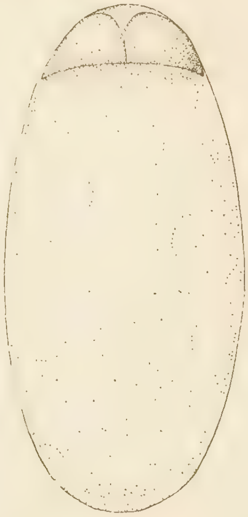

FIGURE 3.—*Anchoviella epsetus.* Egg in 2-cell stage

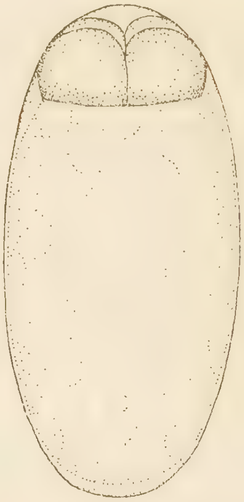

FIGURE 4.—*Anchoviella epsetus.* Egg in 4-cell stage

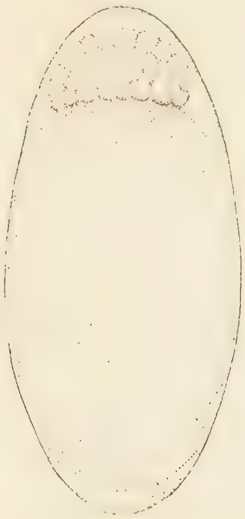

FIGURE 5.—*Anchoviella epsetus.* Egg in advanced cleavage stage

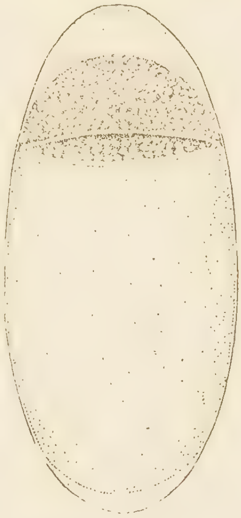

FIGURE 6.—Egg in cleavage stage, farther advanced than in Figure 5. Note bell-shaped blastoderm

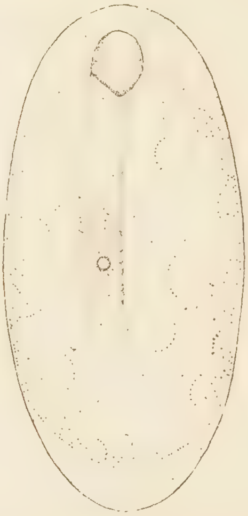

FIGURE 7.—*Anchoviella epsetus.* Egg with small embryo

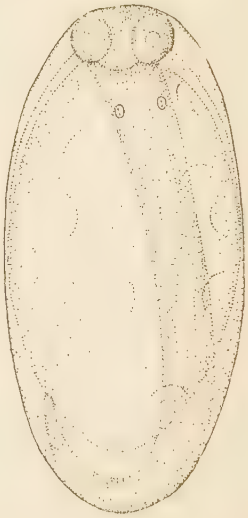

FIGURE 8.—*Anchoviella epsetus.* Egg shortly before hatching. Heart action is evident at this stage

Newly hatched fish 3.6 millimeters long.—The newly hatched fish is very long and slender, averaging close to 3.6 millimeters in length. It is highly transparent, having a slight greenish shade on the head, but no definite chromatophores. The head is somewhat decurved, and the body segments (myomeres) are very distinct. The fin folds are continuous, except where broken by the vent, which is placed slightly behind the beginning of the posterior fourth of the body. Heart action is evident slightly in advance of the auditory canal, but a blood stream is not visible.

The newly hatched *A. epsetus* apparently is more active than most other forms that have been hatched in the laboratory at Beaufort. It most frequently descends to the bottom of the vessels used in hatching the eggs, but it may swim to the surface or occupy any part of the available space. In a period of 24 hours after hatching the yolk is mostly absorbed, the fish has reached a length of about 4.0 millimeters; and in the laboratory, since feeding experiments have failed, the fish usually dies about this time. There has been some advancement in the development of the mouth; the fin fold remains continuous; the head is still slightly deflected; and no chromatophores have appeared, the larvæ still being highly transparent. (Fig. 9.)

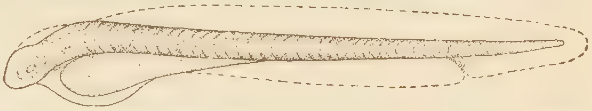

FIGURE 9.—*Anchoviella epsetus*. Newly hatched fish, 3.6 millimeters long

Specimens 5.0 millimeters long.—Specimens of this length and until the anal fin is sufficiently developed to admit the enumeration of the rays, at a length of about 9 to 10 millimeters, apparently can not be separated definitely from *A. mitchilli*. The body remains very slender at a length of 5.0 millimeters, and without chromatophores, except for a row of about five very small elongate ones situated near the ventral outline posterior to the head. Muscular rings remain quite evident and in addition to the rings, cross striations are present. The mouth is large; and the gape is quite oblique, extending to the eye. The alimentary canal is plainly visible and largely separate from the body; that is, it does not appear to be covered by the body wall, being attached loosely to the trunk by connective tissue only.

Superficially, the intestine gives the appearance of being coiled. Upon closer examination and dissection it is found, however, that the alimentary tract is almost a straight tube and the "coils" are muscular rings in the thin body wall. In some specimens the dorsal and anal fins already have become rather indefinitely differentiated at a length of 5.0 millimeters. The fins do not become evident, however, until a length of at least 6 millimeters is reached, and generally the rays can not be definitely enumerated until a length of about 10 millimeters is attained. The pectoral fins are just becoming evident at a length of 5 millimeters although rays are not developed. Ventral fins are not visible but the caudal fin is partly developed. The notochord is bent slightly upward posteriorly, extending into the partly developed caudal fin. (Fig. 10.)

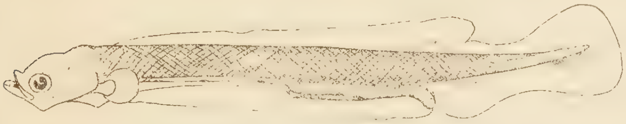

FIGURE 10.—*Anchoviella epsetus*. From a specimen 5.6 millimeters long

Specimens 10.0 millimeters long.—The body has become slightly less slender, the mouth is still terminal and oblique, and the gape extends somewhat past the anterior margin of the eye. Ventral fins are still missing; the dorsal and anal are now sufficiently well developed to admit of a fairly accurate enumeration of the rays. Since *A. epsetus* rarely has more than 20 rays in the anal fin, whereas *A. mitchilli* generally has about 26, the two species may now be definitely separated by this character. The caudal fin is well developed and definitely forked. The notochord is bent abruptly upward posteriorly, ending at the base of the upper rays of the caudal fin. Muscular rings are still faintly visible, at least in the caudal region, and pigmentation consists of a few dark points on the median line of the chest and along the ventral edge extending from the anal base to the caudal fin. A definite invagination of the alimentary canal has not yet taken place as it remains loosely attached to the trunk. (Fig. 11.)

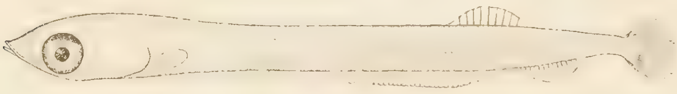

FIGURE 11.—*Anchoviella epsetus.* From a specimen 9 millimeters long

Specimens 15.0 millimeters long.—A somewhat further deepening of the body has taken place, although it is still much more slender than in the adult. The mouth remains terminal, but the gape now reaches well beyond the posterior margin of the eye, and the jaws are somewhat curved. The ventral fins first appear when the fish is about 13 millimeters long, and they are quite well developed at a length of 15 millimeters. The tail is now definitely homocercal and the notochord no longer remains visible. Muscular rings are still evident, but they are bent forward on the sides. Pigmentation remains essentially as it was at a length of 10 millimeters. However, in addition to the dark chromatophores on the chest and the ventral side of the body, extending backward from the base of the anal, there is now a considerable amount of dark pigment on the upper margin of the eye. The alimentary canal, anteriorly, is fairly definitely inclosed by the body wall. Posteriorly, however, the invagination is not complete. (Fig. 12.)

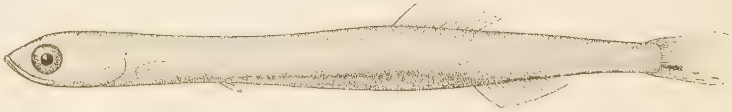

FIGURE 12.—*Anchoviella epsetus.* From a specimen 17 millimeters long

Specimens 25.0 millimeters long.—The differences between fish 15.0 and 25.0 millimeters in length are not great. The gradual deepening of the body has progressed slowly. A fish 25.0 millimeters long remains much more slender, however, than the adult, for the depth is contained about 8.0 times in the length to the base of the caudal fin, whereas in the adult the depth goes into the length about 4.5 times. The mouth is no longer strictly terminal, as it has become slightly inferior. The jaws, however, remain slightly curved; that is, the mouth is bent upward anteriorly. Pigmentation has progressed somewhat. A continuous dark line is present on the median ventral line, reaching from the gill covers to opposite the base of the pectorals. Two or three vertically elongate dark spots have appeared just behind the opercle, and in some specimens several other smaller and less definite dark spots are present. A row of about seven dark spots has developed near the ventral edge of the abdomen, between the pectoral and ventral fins. The dark chromatophores along the base of the anal and on the ventral line of the caudal peduncle remain, forming an almost continuous dark line posterior to the base of the anal. A few dark spots also have appeared at the base of the caudal and on the fin itself. The alimentary tract is now quite definitely inclosed in the body wall. (Fig. 13.)

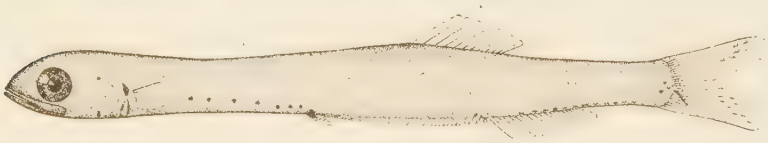

FIGURE 13.—*Anchoviella epsetus.* From a specimen 23.5 millimeters long

Specimens 35.0 millimeters long.—The most pronounced change that has taken place since a length of 25.0 millimeters was reached is in the shape of the mouth which has become definitely inferior, very nearly horizontal, and the maxillary reaches almost to the margin of the opercle, as in the adult. The conical, projecting snout, characteristic of anchovies generally, is fully developed. Pigmentation has now appeared on the back of the fish and particularly in the concentration of chromatophores forming a brownish area on the head. The silvery lateral band has appeared, but it remains quite narrow and rather indistinct. A further deepening of the body has taken place, and the depth is contained about 6.0 times in the length. Scales are not evident on the specimens in hand. (Fig. 14.)

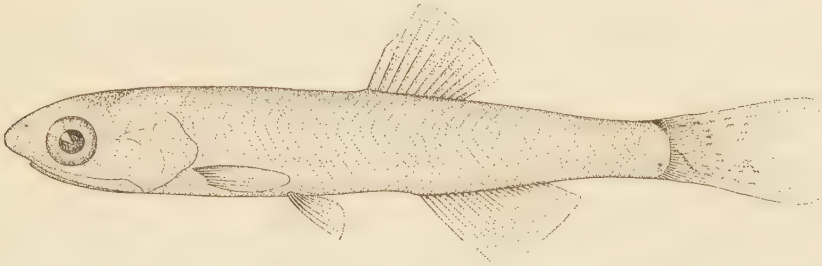

FIGURE 14.—*Anchoviella epsetus.* From a specimen 39 millimeters long

Specimens 45.0 millimeters long.—At this length the young fish has virtually all the characters of the adult and it may be recognized readily as this species. The body is very nearly as deep as in adult fish; the silvery lateral band is clear and distinct; and scales, or at least scale markings, are present. Owing to the deciduous nature of the scales they often are lost, leaving only scale markings on the body. (Fig. 15.)

DISTINGUISHING CHARACTERS

The number of rays in the anal fin constitutes the most reliable character for the separation of *A. epsetus* from *A. mitchilli.* However, after the dorsal and anal fins become well developed the two species may be separated more conveniently by the relative position of the dorsal and anal fin, and, also, by the position of the vent with respect to the origin of the dorsal. That is, in *A. epsetus* the origin of the anal is under the middle of the dorsal base, and the vent is definitely posterior to a vertical line from the origin of the dorsal. In *A. mitchilli,* on the other hand, the origin of the anal is only slightly behind the origin of the dorsal; and the vent is under, or more usually slightly anterior to, the origin of the dorsal fin. After *A. epsetus* reaches a length of about 45 millimeters it has a broader and a much more distinct silvery lateral band than its relative.

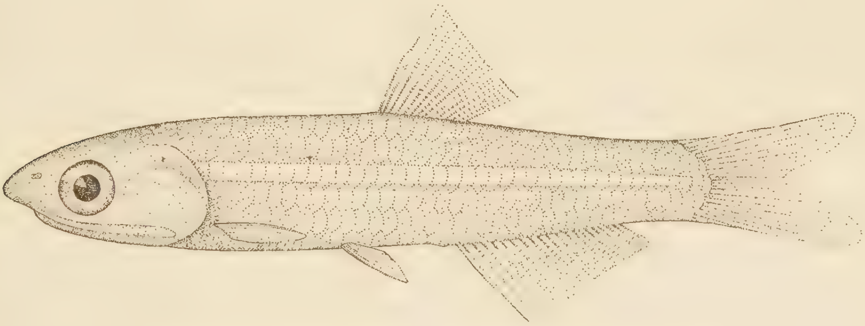

FIGURE 15.—*Anchoviella epsetus.* From a specimen 46 millimeters long

DISTRIBUTION OF YOUNG

Both species are hatched at the surface from floating eggs, as stated elsewhere, but some of the young appear to descend to the bottom at a very early age. In towings made with 1-meter nets when two nets were operated simultaneously, one at the surface and the other on the bottom, young anchovies 12 millimeters and less in length (larger fish seldom were caught in the townets) were taken 57 times at the surface and 86 times on the bottom. Some of the collections, both from the surface and the bottom, contain numerous fish, indicating that young (larval) anchovies, at times and in some places, may be numerous at the surface as well as on the bottom. The fact that they were taken more frequently in the bottom than in the surface tow appears to show, however, that these young may be more commonly present on the bottom, but it seems quite certain that they may occupy any depth within the area where the collections were made.

Very young anchovies were taken in abundance over the entire area in which towings were made, extending from stations 15 miles off Beaufort Inlet, through Beaufort Harbor, and throughout the salt and brackish estuary of Newport River.

After the young reach a length of about 12 millimeters and above, they may be taken with fine-meshed seines in shallow grassy areas which are favorite haunts of the adults also. The fish are not confined to the shallow, grassy water, however, as old and young are obtainable in the deeper waters with suitable collecting nets.

GROWTH

Young anchovies grow rapidly. According to collections made with a bobinet seine which permitted the escape of many of the smaller young, the average length of the fish of the O class of *A. epsetus* taken by this method of collecting was 28.3 millimeters (99 fish measured) in June, and the maximum length was 43 millimeters; in July, the average length had increased to 41.3 millimeters (157 fish measured), and the largest fish was 65 millimeters long; in August, the average length was 55.5 millimeters (218 fish measured), and the maximum length was 83 millimeters; and in September, the average length had increased to 61.1 millimeters (200 fish measured), and the largest fish of the O class taken was a little smaller than the largest of the previous month, as it had a length of only 78 millimeters. The measurements do not show the actual average length of the fish of the O class, for the earlier months at least; for the smallest young are not included, as already explained. For the later months (August and September) the fish taken probably are fairly representative. The measurements at least show the approximate rate of growth of the larger young during the first summer. Since *A. epsetus* frequently is sexually mature at a length of 75 millimeters (3 inches), it is quite certain that at least the early young of each spawning season reproduce the following season; that is, at the age of 1 year.

The rate of growth in *A. mitchilli* is much more difficult to follow, largely because of the longer spawning season and also partly because of the smaller size attained. It is reported elsewhere that small young (12 millimeters long) were taken in December, and these fish, because of slow growth during the winter, are still rather small when the new brood begins to appear the following May. The result is that some of the O class and some of the smaller fish hatched late in the previous season soon intergrade in length, and the measurements made are of no value in separating them. The younger fish (O class) appear to be more scantily pigmented, however, and they accordingly are more nearly transparent and more delicate in general appearance. Fish having this appearance of early youth have been found in a gravid condition in the latter part of July and in August when only 45 to 50 millimeters in length. If the foregoing interpretation of age be correct, then it would follow that the early and largest young of the season of *A. mitchilli* may spawn at an age of 2½ to 3 months. If these small delicate-looking fish are not young ones, then they probably are not *A. mitchilli*, but this we have not been able to demonstrate to date.

FOOD

The food of *A. epsetus* when it reaches a length of about 20 millimeters consists largely of copepods. Prior to that time it appears to feed on such minute organisms that they are not visible, except under high magnification, and no study of the stomach contents of the very small fish has been made. As the fish increases in length it takes copepods in greater numbers; and this diet often is supplemented by minute gastropods, an occasional ostracod, and rarely by an annelid worm. Adult fish continue to feed on copepods but include more ostracods, annelids, small gastropods, some minute bivalve mollusks, and occasionally Mysis. The food of *A. mitchilli* has not been studied.

ORTHOPRISTIS CHRYSOPTERUS (Linnæus). Pigfish; hogfish

The pigfish or hogfish is known from New York to Mexico. It is taken in commercial abundance in southern Maryland, Virginia, North Carolina, and on both coasts of Florida; but, oddly enough, it does not appear in the statistical records of the Bureau of Fisheries from South Carolina and Georgia, where it does not seem to occur in commercial numbers. It is most abundant in North Carolina, where 385,270 pounds were marketed in 1923. The value of the pigfish, to North Carolina at least, should not be judged by the pounds marketed alone, as it offers sport to many anglers. Although the pigfish does not rank high as a game fish, it nevertheless holds a place of some importance; for it is the first fish in the harbors in the spring to take the hook, and it remains in the salt-water sounds and estuaries in North Carolina throughout the summer and may be caught there by the amateur sportsman, as well as by the more experienced angler, at such times when more desirable species are not biting. The pigfish reaches a maximum weight of about 2 pounds, and examples weighing from 1 to 1½ pounds are not unusual. It offers fair resistance when hooked, and its "grunt" may be heard before the fish is landed.

The pigfish as known in North Carolina waters, is distinctly a shore and shallow-water species, seeking its food principally on the bottom. It feeds largely on crustaceans, worms, and mollusks. Shrimp and fiddler crabs are good pigfish bait.

Its habit of feeding on the bottom, and especially on worms, causes the pigfish in midsummer sometimes to include in its diet Balanoglossus—a wormlike chordate which is strongly scented with the odor of iodoform. The scent of this "worm" penetrates the flesh of the fish, and occasionally examples are caught which have a distinctly bad odor and taste. This detracts somewhat from its value as a food fish. Fish that have fed on Balanoglossus, colloquially, are said to have a "ticky taste." It must be understood, however, that the great majority of the fish taken during the summer are not ticky and they do not have this taste at all in the spring and autumn, when Balanoglossus probably does not emerge from its burrows and is not available. The flesh of the pigfish is rather dark in color, is firm, and ordinarily of good flavor and rather highly esteemed.

The pigfish, as already stated, inhabits the local shore waters, the salt-water sounds, and estuaries throughout the summer, arriving in March and April and disappearing again the end of October and during the first half of November. Its winter home is not definitely known. No pigfish have been taken during the winter in catches made with a 30-foot otter trawl operated by the laboratory crew off Beaufort Inlet in depths as great as 10 fathoms. The local sea bass (blackfish) fishermen, however, take a few throughout the winter on the sea-bass grounds about 20 miles offshore in depths of about 18 fathoms. The hooks used for the sea bass are rather too large for the smaller mouthed pigfish, and the number taken may be no indication of the numbers actually present. Southward and northward migrations do not appear plausible for the reason that the pigfish does not appear in commercial abundance in the fisheries of South Carolina and Georgia, although it is a species of some commercial value in Florida. If the large body of pigfish which undoubtedly leaves the shallow waters of North Carolina and Virginia at the approach of cold weather migrated southward to return the following spring, one would expect the species to appear, at least in the early spring and late autumn, in commercial quantities in the shore fisheries of South Carolina and Georgia. Since this is not the case and since a few, at least, are known to occur on the sea-bass grounds after they leave the shore waters, it seems more probable that the fish migrate offshore rather than southward.

Wherever the winter habitat of the pigfish may be, it does not appear to offer the abundance of food that the fish find in their summer home, for they leave well fed and fat and return in the spring in a considerably emaciated condition, a fact well known to fishermen and dealers. Hildebrand and Schroeder (1928, pp. 259–260) have shown, from a limited number of length measurements and weights, that fish taken in May in Chesapeake Bay weighed considerably less than fish of equal lengths caught in October. The following table, based on fish taken at Beaufort in April and May and in October and November, shows a similar relationship.

Table 1.—*Comparison of lengths and weights of pigfish taken in the spring and autumn*

Date	Length	Weight	Date	Length	Weight	Date	Length	Weight
	Inches	*Ounces*		*Inches*	*Ounces*		*Inches*	*Ounces*
May 20	8.0	3.4	May 27	9.5	5.75	Nov. 1	8.9	6.8
May 27	8.0	3.5	May 12	10.75	10.0	Do	9.25	8.9
Apr. 22	8.9	6.1	Oct. 15	8.0	4.2	Do	9.5	9.4
Do	8.9	5.7	Nov. 1	8.0	4.7	Nov. 7	10.5	11.0
Apr. 15	9.25	5.0	Oct. 23	8.8	6.3			

Why does the pigfish leave the shallow shore waters of North Carolina (and northward) when cool weather comes? This question quite logically comes to mind in connection with the foregoing discussion. It can not be definitely answered at this time. It is thought that the main reason for its withdrawal is a disagreeable temperature, although a decrease in its food supply may be a secondary cause. Small crustaceans and at least some small fish—two of its principal foods—are present all winter. For that reason it would seem probable that the fish leaves because the temperature of the water is not agreeable rather than for the purpose of seeking better feeding grounds in which it does not seem to be very successful, as already shown. Since the pigfish is a member of a family of tropical fishes—namely, the grunts—and the only one of the family occurring north of Florida in commercial numbers, a dislike for low temperatures might be expected.

It appears to be of interest to mention, also, that the larger fish are the first ones to migrate away from the local waters in the autumn. No large fish appeared in our collections after the early days of November and some evidence, as shown subsequently, has been obtained indicating that even the largest young of the current season—namely, the largest representatives of the O class—leave the shallow waters somewhat earlier than the smaller fish of the same year class. On the other hand the older and larger fish are the first ones to return the following spring, some in March and many more in April.

The smaller young of the previous year, now the I class, do not appear to get back until about June, for the smallest individual taken of the older year classes in April was 175 millimeters long; the smallest one caught in May was 125 millimeters in length; and in June the smallest fish, evidently belonging to the 1-year class, were 105 millimeters long. (One specimen, probably belonging to this class, had a length of only 92 millimeters.) Fish of the last-mentioned size compare well with the smallest fish of the O class taken in November, which were 87 millimeters in length. Owing to the emaciated condition of the fish when they return from their winter habitat, one would not expect rapid growth. Their growth after returning to their summer home, however, appears to proceed rather rapidly, for the smallest fish in our collections assigned to the 1-year class taken in July was 145 millimeters long; the smallest ones in August were 150 millimeters long; in September and October the smallest fish for each month were 160 and for November 165 millimeters. It is rather certain that some of the smaller individuals of the I class are missing in the catches for July, as it is improbable that fish only 105 millimeters long in June had attained a length of 145 millimeters in July. Furthermore, the gap in length measurements for June between the O and I classes had almost closed, whereas in the July measurements an interval reappears, extending from 112 millimeters, the largest representatives of the O class, to 145 millimeters, the smallest representatives of the older year classes. In August the gap in the measurements again is almost closed, and it remained so during the rest of the summer.

A record of water temperatures taken daily at 4.30 p. m. at the laboratory pier shows a rather close similarity when comparisons are made for the months during which the principal pigfish migrations take place. That is, the temperature in March, when the fish usually begin to return to the shallow waters, are near those that prevail in November when the last ones leave. Similarly, the temperatures for April and October, the months when the main body of pigfish migrates, are not very different. The range in temperature and the averages, expressed in degrees centigrade, for the 4-year period, namely, 1926 to 1929, for the months during which the principal pigfish migrations take place locally, are shown in the accompanying table.

TABLE 2.—*Comparison of the average water temperature (centigrade) at Beaufort, N. C., in March and April with that of October and November from 1926 to 1929*

Month	Minimum	Maximum	Average	Month	Minimum	Maximum	Average
March	6	22	14.3	October	16	30	22.2
April	13	23	18.3	November	8	25	16.3

Since the temperatures given in Table 2 were taken just beside one of the principal channels between Beaufort Harbor and the estuary of Newport River, many fish in their migrations no doubt pass the place where the records were obtained;

and, therefore, the temperatures must be quite representative of those which prevail when the pigfish migrates. It is shown by the table that the spring temperatures (March and April) are a little lower than the autumn temperatures (October and November) when the fish perform their principal migration. It has been pointed out elsewhere that the larger and older fish are the first ones to leave the shallow waters in the autumn, and that they are also the first ones to return in the spring. Why the older fish lead the migrations is not well understood. Possibly they "know" the route better, and again they may "understand" better the significance of cooling and warming waters. Then, too, in the spring they may be driven on by the "urge" to spawn.

It seems in order to state here in defense of the foregoing statements and the use of the terms "know" and "understand" that one is driven to the conclusion by numerous observations in support thereof that the older fish of nearly all species are much better able to protect and to take care of themselves than the younger ones. In other words, intelligence in fishes, as in higher vertebrates, increases considerably with age. An instance of a seemingly high fish intelligence of adults may be seen in overflowed lands. Few large or adult fish become stranded when the water recedes, although countless young perish in pools. Yet there is no doubt that the large fish follow the flood waters. They seem to know, however, when it is time to return to the main body of water. This sense of self-protection appears to be possessed alike by both fresh and salt water species. It seems reasonable, therefore, to expect the older pigfish, because of their superior intelligence, to lead the migrations which no doubt are made in the interest of self-preservation.

SPAWNING

Almost nothing appears to have been known prior to the present investigation in regard to reproduction in the pigfish, for we find in the literature only the general statement that spawning occurs in the spring (May and June).[3] We find nothing relative to the place of spawning, the type of eggs produced, and the characters of the young—all discussed subsequently in this paper. Concerning the rate of growth of the young, also discussed herein, we find only Taylor's paper (1916, pp. 319–324) based partly on length measurements and partly on scale studies. Taylor's account appears quite inadequate to us, especially as he seems to have confused the O class with the I class. It is not particularly surprising, however, that such fundamental information is missing in regard to the pigfish, as equally as little is known about dozens of other common species of even wider distribution and greater economic value.

During the present investigation, extending over four seasons, recently hatched young were taken sparingly as early as March 16 (1927 only), although the eggs did not appear in the tow until April 13 (1928). The latest date upon which the eggs were observed was June 22 (1927), and they were most numerous each year during May. It may be concluded, therefore, that spawning may begin at Beaufort as early as the middle of March, that it ends near the latter part of June, and that the principal spawning period occurs in May. This conclusion is supported also by tables of measurements of young fish and by a growth curve included in this paper. (See Tables 3 and 4 and fig. 39.)

Gravid fish are particularly numerous along the inside shores of Bogue and Shackleford Banks during the spawning season, and it is here that the greatest concentration of eggs occurs. It is rather certain that the comparatively quiet waters on the inside shores of these banks constitute the chief spawning grounds of the pigfish in the vicinity of Beaufort. However, some spawning certainly takes place elsewhere within the harbor, in the estuaries, and along the outer shores of the banks, for the eggs are distributed too generally throughout these waters to be carried there by tides and currents. Then, too, eggs in the early cell-divisions stages were taken just off the laboratory pier. Since the development proceeds very rapidly, as shown elsewhere, the eggs must have been cast almost where taken. Furthermore, ripe or nearly ripe fish may be taken in all of the waters where the eggs occur. All the young (larvæ) secured in March were taken outside of Beaufort Inlet, and some of them as far offshore as 7 miles. Towings were made in inside waters at the same time but yielded no pigfish larvæ. This apparently would indicate that spawning may begin somewhat earlier along the outer shores of the banks than it does on the inside shores.

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[3] A preliminary account of a part of the present investigation, dealing principally with the embryology of the pigfish is given by Towers (1928, pp. 622–624).

In general the larger fish spawn first and the late spawners consist of small individuals which may be reproducing for the first time. This information is deduced from the observation that the roe in large fish early in the season is in a more advanced state of development than it is in smaller fish, whereas late in the season the large fish usually are spawned out and the smaller ones still contain roe. The spawn apparently is not all cast at one time, as the examination of the ovaries shows that the eggs contained therein are not all equally developed. Furthermore, partly spent fish are seen frequently.

DEVELOPMENT OF EGGS AND YOUNG

Spawning appears to take place, exclusively, early in the evening, mostly between 6 and 8 o'clock. It was positively necessary to collect eggs at this time to get the early cell stages, for they could not be obtained at any other hours. Fish confined in tanks laid eggs at that time only. Eggs taken in the tow generally are in two remarkably uniform stages of development, which appears to be further proof that spawning takes place only at definite intervals and over short periods of time, the eggs in the more advanced stage of development having been laid a day earlier than the others, as explained more fully subsequently. It may be remarked here that early evening spawning apparently is quite usual among local marine species.

Eggs.—The eggs were taken, often in great abundance, in meter townets, and they were secured also from the overflow of tanks in which ripe or nearly ripe fish had been confined. The eggs generally were cast on the first or second evening of confinement. Thereafter very few were obtained, for the pigfish, like some other species, appear to hold the spawn and refuse to cast it in confinement, unless quite ripe when caught. Stripping and artificially fertilizing the eggs failed. This is not surprising now that it is known that spawn is cast only during a few hours in the evening, and it is not recalled that artificial fertilization was attempted at that time.

The eggs are buoyant in sea water. They are spherical and vary in diameter from 0.7 to 0.8 millimeter with an average of 0.75 millimeter, as shown by measurements of 100 newly spawned eggs caught in the overflow of a tank in which ripe fish were confined. They are unattached but have a tendency to collect and to become arranged in regular series in the glass sediment dishes used for hatching them. The eggs are highly transparent and usually contain one comparatively large oil globule which has an average diameter of 0.16 millimeter and occupies the upper pole; that is, the pole opposite the blastodisc. Occasionally an egg has two and rarely three oil globules. When more than one globule is present they are proportionately smaller than the single oil globule. The eggs float with the oil globule or globules uppermost and are never seen otherwise.

The similarity of the eggs of the pigfish and those of the white perch (*Bairdiella chrysura*)—the latter for the most part correctly described and figured by Kuntz (1914, p. 4, figs. 1 to 15)—is so great that they are confused easily. Confusion is especially liable to occur, because the eggs of both species are taken in the same areas and in the same towings during the greater part of the spawning season of the pigfish, as the spawning seasons of the two overlap. The separation of the eggs is especially difficult during the early stages, or until the embryo becomes well outlined, and for that reason it seems advisable to state the differences noticed. In size the eggs are nearly identical. The range, as shown by the measurements of 100 perch eggs spawned in a tank in which ripe fish were confined, is 0.66 to 0.72 millimeter with an average of 0.686 millimeter. Although the eggs of the perch according to these measurements average a little smaller than those of the pigfish, so many are identical in size that they can not be separated on this basis. The eggs of both species commonly have a single oil globule. That of the perch egg averages slightly larger (0.18 millimeter) than that of the pigfish egg (0.16 millimeter), but the difference is so slight and so many are of equal size that the character is of little use in making identifications. However, the oil globule in the perch egg seldom is as clear as that in the pigfish egg. Furthermore, the oil globule in the perch acquires dark greenish specks in the advanced cleavage stage, which increase in number and become quite prominent when the embryo becomes well outlined. At this time the granular specks appear on the embryo also. These markings persist both on the oil globule and on the embryo until hatching and for a short time (24 hours or so) after hatching. In the pigfish, on the other hand, dark specks, if they appear at all, are present only during the early embryonic stages and they disappear when an advanced embryonic stage is reached. When present they are fewer and smaller and, therefore, less prominent than in the perch.

The position of the oil globules in relation to the embryos forms a ready and reliable recognition mark when an advanced embryonic stage is reached, and this character may be employed also in separating the newly hatched young of the two species. In the pigfish the oil globule occupies an anterior position with respect to the embryo. That is, it lies under or near the ventral surface of the head, whereas in the perch it occupies a posterior position, lying well behind the head. Similarly, in the newly hatched pigfish the oil globule lies near the anterior periphery of the yolk sac, under the head of the fish, whereas in the perch it occuppies a position near the posterior periphery of the yolk sac, on the ventral surface of the abdomen.

Attention is called to the fact that Kuntz (1914, p. 4) gives the range in size of the perch egg as 0.7 to 0.8 millimeter, whereas the range obtained by us, as already stated, extends from 0.66 to 0.72 millimeter. It is evident from the range in size given that Doctor Kuntz included eggs of a larger size. It seems probable that he considered a certain larger egg, apparently always found in the tow with the perch egg herein described, as identical with the smaller egg which now is known definitely to be a perch egg. This larger egg appears to be identical, except for size, with the smaller one during the early developmental stages. In the advanced embryonic stage it, however, acquires a more profuse dotting with dark-green granules. The fish hatched from this egg is slightly larger, as would be expected, and it contains more pigment than the larva hatched from the smaller egg. This larger egg, as to size, is distinct from the smaller perch egg, as its range in size is about 0.8 to 0.88 millimeter and its average is close to 0.84 millimeter. It seems probable, therefore, that this larger egg is from a different species. However, we have not yet succeeded in determining by which species it is produced.

Segmentation and the development of the embryo.—Segmentation occurs very quickly after fertilization takes place. (Fig. 16.) Eggs held in glass sediment dishes at a temperature varying from 67° to 69° F. reached the 2-cell stage (figs. 17 and 18) within one-half hour after fertilization, the 4-cell stage (fig. 19) within three-fourths of an hour, and an advanced cleavage stage (fig. 21) within 6 hours. Twelve hours after fertilization the germ ring had become visible in many of the eggs, within 24 hours the embryo was well formed (fig. 22), and at 36 hours the more advanced eggs began to hatch (fig. 23). Early in the season the eggs developed less rapidly, but late in the season, when the temperatures were running high in the laboratory, development proceeded even more rapidly than described in the foregoing lines. It became very difficult, though, to hatch the eggs at the higher temperatures, as many of them died in various stages of development, apparently due to the excessive heat. The incubation period at the temperatures (ranging from about 60° to 85° F.) that prevail in the local waters during the spawning season, judging from results obtained in the laboratory, probably ranges from about 36 to 72 hours—the shorter period of time being required late in the season when temperatures are high and the longer period earlier when temperatures are low.

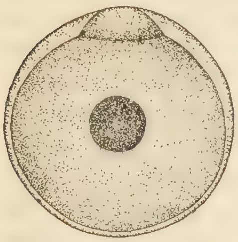
FIGURE 16.—*Orthopristis chrysopterus.* Egg with fully developed blastodisc, a few minutes after fertilization. Normal egg about 0.75 millimeters in diameter

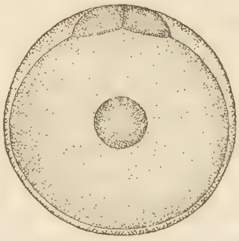
FIGURE 17.—*Orthopristis chrysopterus.* Egg in 2-cell stage, about a half hour after fertilization

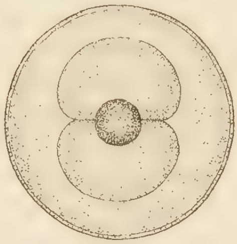
FIGURE 18.—*Orthopristis chrysopterus.* Egg in 2-cell stage, same as Figure 17, surface view

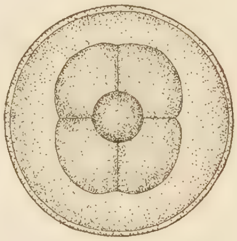
FIGURE 19.—*Orthopristis chrysopterus.* Egg in 4-cell stage, surface view, about three-fourths of an hour after fertilization

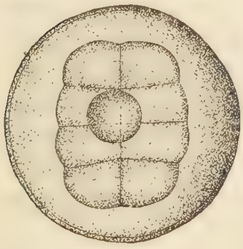
FIGURE 20.—*Orthopristis chrysopterus.* Egg in 8-cell stage, surface view, about one hour after fertilization

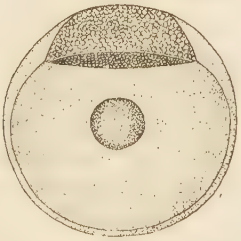
FIGURE 21.—*Orthopristis chrysopterus.* Egg in late cleavage stage, side view

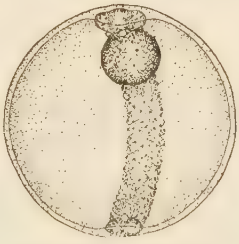
FIGURE 22.—*Orthopristis chrysopterus.* Egg embryo, showing distribution of chromatophores, about 24 hours after fertilization

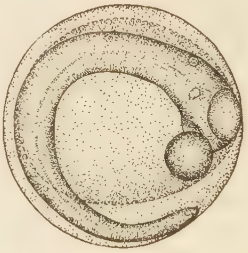
FIGURE 23.—*Orthopristis chrysopterus.* Embryo shortly before hatching, about 36 hours after fertilization. Heart action is evident at this stage

The mode of segmentation is quite usual for a teleost, and it does not differ noticeably from that described for the white perch (*Bairdiella chrysura*) by Kuntz (1914, pp. 4 and 5). The blastodisc becomes somewhat elongate just before the first cleavage occurs, and then it is cut at right angles to the longer axis. (Fig. 17.) The second cleavage plane cuts the first at right angles. (Fig. 18.) This manner of cleavage continues as long as the process can be observed.

The embryo shortly before it is released almost completely encircles the periphery of the egg. (Fig. 23.) The embryo is capable of considerable movement at this time, and the pulsation of the heart is clearly visible. Circulation of the blood, however, is not evident. Definite pigment spots are absent at this stage as already indicated, the auditory canals are plainly visible, the eyes appear to be extraordinarily large, and the single big oil globule which remains unchanged throughout the incubation period and for some time afterwards, lies opposite the ventral surface of the head of the embryo.

Newly hatched fish.—The newly hatched fish is only about 1.5 millimeters long. Its head is deflected rather prominently, and it contains a relatively large amount of yolk. The larva is quite helpless at this stage. It floats on its back, being capable of movement in this position only by the use of its free tail. Presumably, the larva is held in the position described—namely, with the ventral surface upward—by the yolk sac in which the large oil globule constantly occupies an anterior position within the sac. At hatching the larvæ have a few greenish spots on the dorsal surface of the head and body, generally placed as follows: A few indistinct ones over the snout, a few larger and more evident ones just behind the head, a pair a short distance behind the auditory canals, another pair above the posterior part of the yolk sac, two over the vent, and two more at mid-caudal length. When the pigment spots are seen from certain angles they give the appearance of crossbars. The oil globule is slightly greenish in color. Occasionally it contains a few rather definite darker spots, but usually spots are missing. (Fig. 24.)

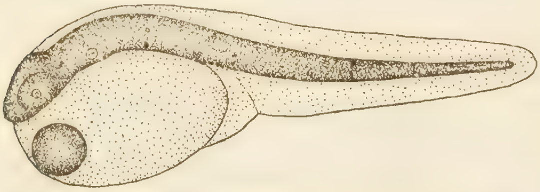

FIGURE 24.—*Orthopristis chrysopterus*. Newly hatched larva with yolk sac. Actual length of fish, 1.5 millimeters

Although the eggs of the pigfish and white perch are very similar, as already pointed out, the separation of the young is easy. In the pigfish the oil globule within the yolk sac lies near the head of the fish. In the white perch the oil globule lies near the posterior periphery of the yolk sac, far behind the head. Furthermore, at hatching nearly the entire fish, as well as the oil globule, in the white perch are dotted with greenish, granular markings, whereas these markings are missing in the pigfish and the color is as described in the foregoing paragraph.

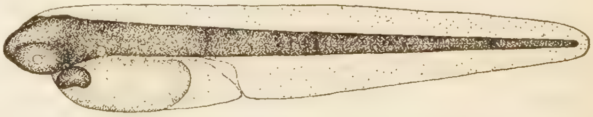

FIGURE 25.—*Orthopristis chrysopterus*. Larva 1 day old, actual length 2.5 millimeters

At a length of about 3.0 millimeters the white perch has become much deeper and stockier than the pigfish. Furthermore, the perch has a large amount of dark pigment on the body, especially over the abdominal mass, when preserved (color markings mostly greenish in life), whereas the pigfish at this size has no definite pigmentation. In fact pigfish have no outstanding color markings until a length of about 15 millimeters is attained, when a dark lateral band has developed.

The young fish attains a length of about 2.5 millimeters within a day or so after hatching. (Figs. 25 and 26.) At this size the body has become quite straight, the pigment spots on the anterior part of the body at first present have become diffuse, but the ones over the vent and at mid-caudal length are very distinct and form more or less definite crossbars. In some individuals the spots behind the auditory canals still persist at this age. The yolk sac has decreased to somewhat less than a fourth of its original size, but the oil globule persists. At this size, or a little later, the fish begins to orient itself in part; that is, it no longer swims on its back but more or less on the side. (Fig. 27.) Usually by the third day at laboratory temperatures prevailing during May and June the yolk is nearly all absorbed, and generally the oil globule, too, disappears about this time. The fish now has attained a length of about 2.8 millimeters, pectoral fins have become evident, and it is able to swim in the usual upright position. It may continue to live for several days longer (a few individuals have lived nine days) in the sediment jars used, but there is no further gain in size and little change in structure. (Fig. 28.)

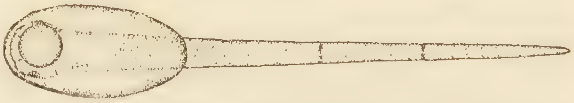

FIGURE 26.—*Orthopristis chrysopterus.* Larva 1 day old, ventral view. Actual length, 2.5 millimeters

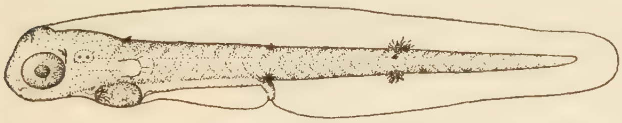

FIGURE 27.—*Orthopristis chrysopterus.* Larva 2½ days old; actual length, 3 millimeters

Specimens 3.1 millimeters long.—Specimens of this size are characterized chiefly by the long, slender tail, the vent being situated well in advance of mid-body length, and by the almost vertical mouth, which is only moderately oblique in the adult. A pronounced hump is present dorsally just behind the eyes; the intestine is attached loosely to the body and distally more or less free. The fin fold is continuous, and the vertical fins remain undifferentiated. Pigment spots are wanting in preserved specimens. (Fig. 29.)

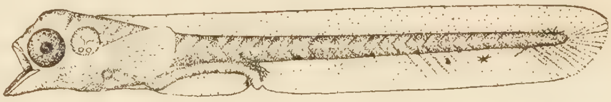

FIGURE 28.—*Orthopristis chrysopterus.* Larva somewhat older than the one represented in Figure 27, but actually a little shorter, 2.8 millimeters long. Note indication of fin rays within fin fold

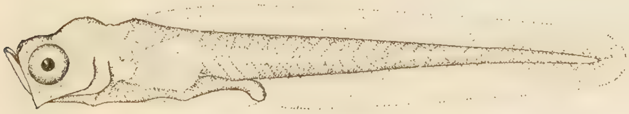

FIGURE 29.—*Orthopristis chrysopterus.* Larva slightly further advanced than one shown in Figure 28. Actual length, 3.1 millimeters

Specimens 4.9 millimeters long.—The body, especially posteriorly, has become deeper; and the only other pronounced change since a length of 3.1 millimeters was reached is in the development of the caudal fin which now has become partly differentiated, rather definite rays having appeared ventrally of the notochord. The notochord has curved upward somewhat, giving a heterocercal appearance to the tail, which is not as pronounced, however, in the pigfish as in several other species studied, especially in the croaker and the spot. (Fig. 30.)

Specimens 6.7 millimeters long.—The deepening of the body posteriorly continues. The caudal fin is now rather well developed and has a round margin. The notochord is curved upward more strongly than previously. The dorsal and anal fins are becoming differentiated but, as yet, do not contain definitely developed rays. An expansion of the fin fold on the distal part of the tail gives the appearance of a third dorsal fin, which, however, fails to develop and gradually disappears. (Fig. 31.)

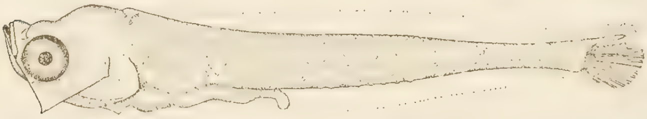

FIGURE 30.—*Orthopristis chrysopterus.* Young fish, 4.9 millimeters long

Specimens 10.0 millimeters long.—The body has continued to increase in depth, and it has become definitely compressed, the depth being contained in the length to the base of the caudal fin about 6.0 times. The mouth is now somewhat less vertical than in the smaller stages, but it remains much more oblique than in the adult. The soft dorsal and anal fins are far enough developed to admit of a fairly accurate count of the rays. The spinous dorsal and the ventral fins remain undeveloped. The caudal fin is well formed, and its margin is somewhat emarginate, approaching in that respect the forked shape of the adult. The notochord, now sharply bent upward, remains only faintly visible. Pigmentation is becoming evident in preserved specimens in the darkened margins of the opercle and preopercle, in the darkened distal ends of the fin rays, and the broken, black crosslines on the caudal fin. (Fig. 32).

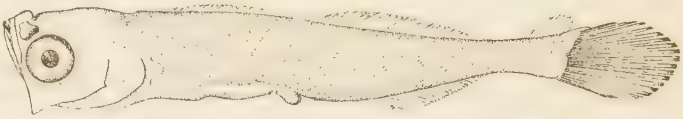

FIGURE 31.—*Orthopristis chrysopterus.* Young fish, 6.7 millimeters long

Specimens 11.0 millimeters long.—The principal changes from the previously described size are in the appearance of the spinous dorsal—a few spines having become slightly developed—and in the first appearance of the ventral fins. The notochord, in its sharply upward-curved position posteriorly, remains only faintly visible. The depth is now contained in the length to the base of the caudal fin about 5.3 times. (Fig. 33.)

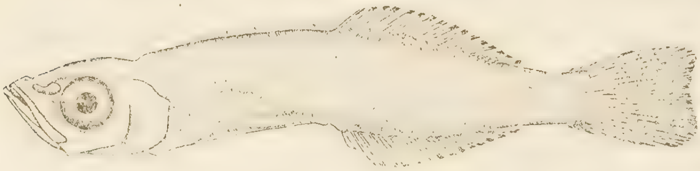

FIGURE 32.—*Orthopristis chrysopterus.* Young fish, 10 millimeters long

Specimens 15.0 millimeters long.—The head and body have increased in depth and are notably compressed, the depth being contained in the length about 4.2 times. The mouth is only slightly more oblique than in the adult. The upward-curved notochord—that is, the heterocercal character of the tail—has completely disappeared. The spinous dorsal is now partly developed, about 7 spines usually having appeared well in advance of, and entirely separate from, the soft dorsal. Variation in this respect has been noticed, as in some specimens of this size the spinous dorsal is further developed than in others. Pigmentation has progressed rather rapidly. A dark lateral band which aids greatly in identification has developed, the lips and snout are more or less dusky, small areas of dark chromatophores are present on the head and on the back, and scattered dusky dots occur along the base of the anal fin. (Fig. 34.)

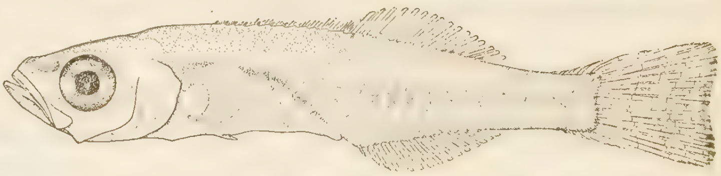

FIGURE 33.—*Orthopristis chrysopterus.* Young fish, 11 millimeters long

Specimens 17.0 millimeters long.—The develoment of the spinous dorsal has progressed rather rapidly. About 10 spines are fairly well developed, and the rudiments of a few more are visible anteriorly. This fin is now definitely joined to the soft dorsal. Pigmentation has become rather general. The dark lateral band, just forming at a length of 15.0 millimeters, has become prominent, and it constitutes a ready recognition mark. The body is almost completely scaled, although not so shown in the accompanying drawing. (Fig. 35.)

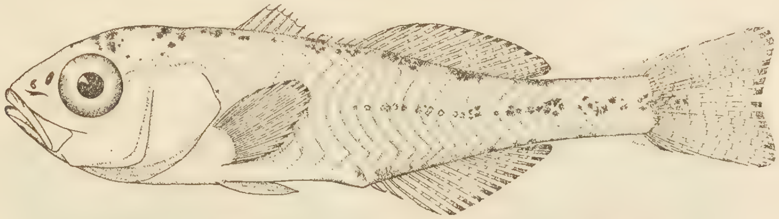

FIGURE 34.—*Orthopristis chrysopterus.* Young fish, 13.5 millimeters long

Specimens 25.0 millimeters long.—The body has become deeper and more compressed although still relatively more slender than in the adult, its depth being contained in the length about 3.0 times, whereas in the adult the depth usually goes into the length to the base of the caudal fin only about 2.4 times. The shape and position of the mouth are essentially as in the adult. All the dorsal spines are developed, and the general outline of the fin is approaching that of the adult. Pigmentation is general. The dark lateral band mentioned in the description of the 17.0 millimeter specimens is prominent and a second one, extending from the nape to the base of the second dorsal, is present. The body is fully scaled, as in the adult, and the ctenoid character of the scales is evident. (Fig. 36.)

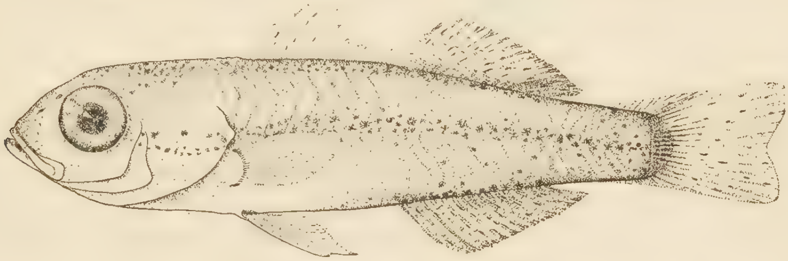

FIGURE 35.—*Orthopristis chrysopterus.* Young fish, 17 millimeters long

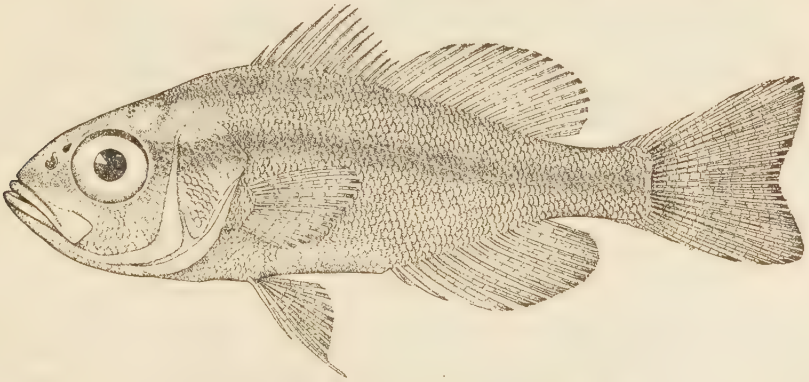

FIGURE 36.—*Orthopristis chrysopterus.* Young fish, 26 millimeters long

Specimens 40.0 millimeters long.—The body has become more strongly compressed, the back is narrow and high, and the general form approaches that of the adult rather closely, the depth now being contained in the length about 2.8 times. The color is rather variable. The dark longitudinal bands, described for specimens 25 millimeters long, often have disappeared, or the lower one may remain visible anteriorly. Occasionally specimens of this size and even larger ones are seen in which the bands remain evident. Some specimens, at least, have indications of dark crossbars. In life, yellow and green horizontal lines are present on the sides and are most prominent on the cheeks and opercles. (Fig. 37.)

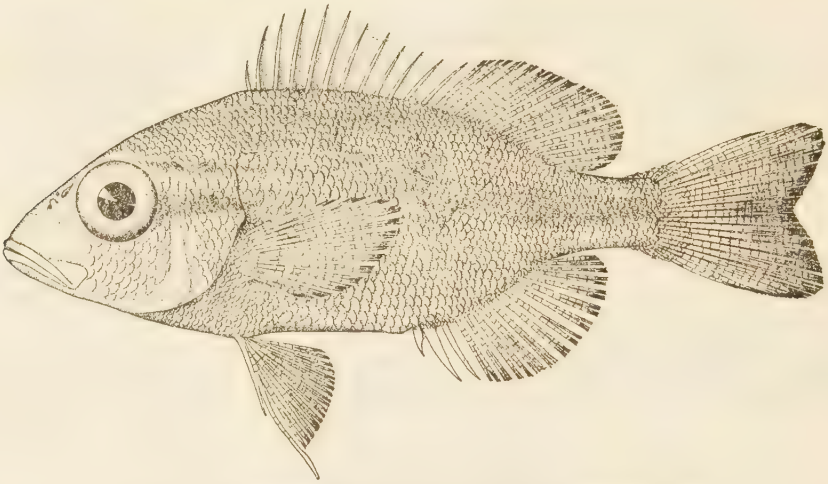

FIGURE 37.—*Orthopristis chrysopterus.* From a fish 38 millimeters long

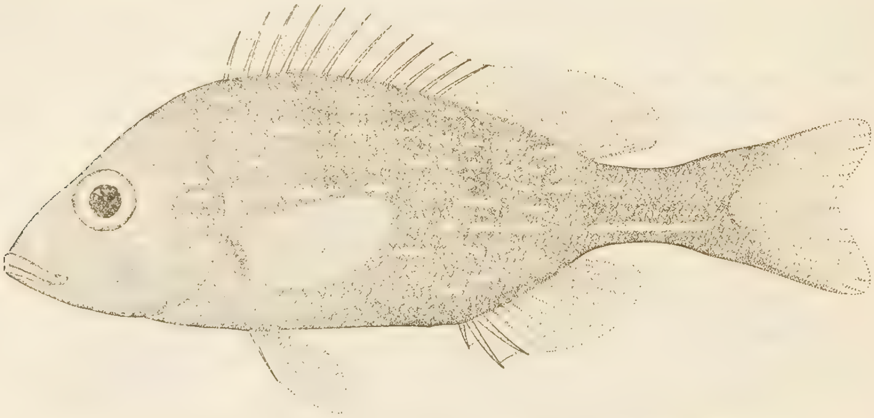

FIGURE 38.—*Orthopristis chrysopterus.* From a fish 70 millimeters long

Specimens 70.0 millimeters long.—The fish now has acquired essentially the form and shape of the adult. The back is prominently elevated, the ventral outline anteriorly is nearly straight, and the snout is pointed. In some specimens the two dark horizontal bands described in smaller fish remain faintly visible, dark cross shades sometimes are present, and in life greenish and yellowish lines are present on sides. A fish of this size is readily identified with the adult. (Fig. 38.)

EXPERIMENTS IN GROWING YOUNG PIGFISH IN CAPTIVITY

Several attempts at feeding and otherwise keeping the young fish alive and inducing them to grow, after the yolk had been absorbed, were made. No artificial food was found that gave any promise of success. Fry placed in glass dishes in the laboratory and supplied with running water, from which it was thought they might secure some natural food, fared no better than those kept in similar dishes without running water. Wooden frames (floats) covered with bolting silk were partly submerged in laboratory tanks, supplied with an abundance of running water. A similar but larger frame was anchored in the harbor. It was hoped that the fish might obtain natural food in this way. However, no fish were recovered from these "floats" if left over a period of several hours. It is believed the young fish are so delicate that they are injured by the roughness of the silk. It was not possible, at least, to transfer recently hatched fish alive on bolting silk from one dish to another, even though they were out of water for only a fraction of a second. Diatom mud was placed in dishes with sea water to which the fry were added after the mud had settled, or again the fish were placed in water decanted from diatom mud. These experiments all failed, and to date no method of growing the young fish in captivity has been found.

Since the fry could not be grown in captivity beyond a length of about 3 millimeters, it became necessary to catch fish of about that size, and larger ones, to obtain and to study all the stages in the development.

The identification of young fish only about 3 millimeters long, unless comparatively large series to connect them with larger or smaller specimens of known identity are available, obviously is difficult. Therefore, the completion of the series was attempted by "patching" out, one grading downward from individuals large enough to be readily recognized because of their resemblance to the adult. A series, ranging from adults downward to a length of 11 millimeters, was obtained within a few months after the work on the egg development was completed. These sizes were obtained with seines, the smaller ones occurring in abundance in shallow water in the immediate vicinity of the station where the bottom was overgrown with eelgrass. The missing sizes (3 to 11 millimeters long), however, were much more difficult to get. It was expected, of course, that they would occur in the tow, especially since the eggs were numerous and rather widely distributed. A few scattering ones were taken from time to time, but they were of such intermediate sizes that they were not recognized either as identical with the recently hatched young or as belonging to the series of larger pigfish already secured. It was not until the third season after this study was begun that the proper sizes were taken in sufficient numbers to complete the series, and then only once and by a mere chance. This particular time the bottom townet, which was being hauled on Newport River a short distance from the laboratory, became well filled with sand. A pailful of this sand was brought to the laboratory, and the missing, and much sought for, sizes of pigfish occurred in abundance in this sand. Although many hauls had been made over the same course with a bottom townet without gathering up sand, pigfish from 3 to 11 millimeters long had been missing almost constantly. It might be inferred from these results that the young pigfish after absorbing its yolk falls to the bottom, where it remains in the sand until a length of about 11 millimeters is attained, when it resorts to shallow water in grassy areas, which are its favorite haunts during its first summer.

Growth.—The study of the rate of growth of the pigfish after its first summer and its span of life, pursued by the junior author, has not progressed far enough to admit of an adequate discussion at the present time. Therefore, the account here is limited almost wholly to the rate of growth of the O class; that is, from the time the fish are hatched in the spring until they leave the local waters in the autumn.

The only published account of the rate of growth and the span of life of the pigfish known to the writers, is by Taylor (1916, pp. 319–324). Taylor's discussion has for its basis a very limited number of length measurements and scale studies. It seems quite certain that Taylor, as stated elsewhere (p. 398) confused and combined the O class with older fish. His graph (fig. 7, p. 321, loc. cit.) shows a peak composed of fish 80 millimeters long. These fish, as shown by the graph (fig. 39), belong to the O class. Taylor's graph does not show a clear division between the O class and older fish, because the measurements very probably were taken over a period of from two to three months (for Taylor's investigation was carried on from the latter part of June until early in September) and the data were not treated separately by months. Since the measurements were taken during a season of rapid growth, overlapping of the young, namely, the O class, with fish of the previous year would be expected over the period of time covered by the investigation.

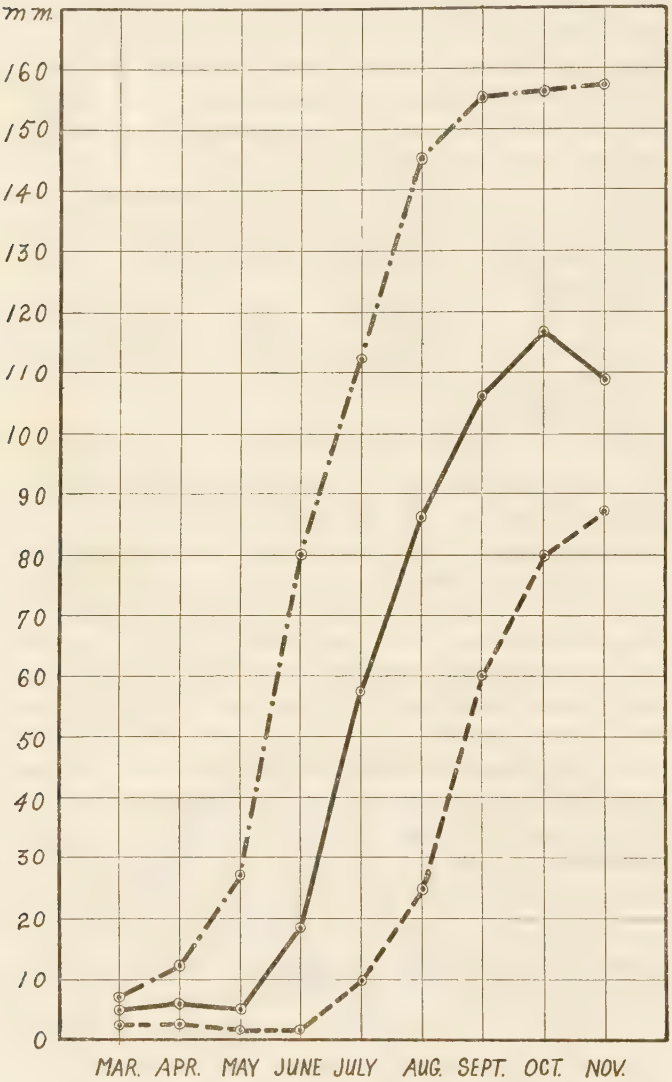

FIGURE 39.—Growth of pigfish (*Orthopristis chrysopterus*) during first summer. Solid line shows average size, dot-and-dash line illustrates maximum size, and dash line shows minimum size. (Based on Table 4)

In the present investigation, when much larger numbers of fish were measured and the data analyzed separately for each month, the division between the O class and the older fish always was so obvious that it seems scarcely necessary to offer a frequency table as evidence.

Prior to June the interval in the measurements of the recently hatched young and the older fish is large. Thereafter, it almost closes. Little, if any, overlapping occurs in the O and I classes, as previously indicated (p. 397); and, at most, only a few individuals could not be placed with certainty.

The apparatus used for collecting young fish--namely, townets, small collecting seines, and small otter trawls—is not adapted to catching many large fish. However, a limited number was taken and measured. An analysis of these data shows nothing distinctive concerning the older year classes and their rate of growth. (See Table 3.) It is evident, therefore, that large series of measurements would be required, if indeed it is at all possible, to separate the older fish into year classes on the basis of length measurements.

Very recently hatched pigfish—2.0 to 2.5 millimeters long—appeared in the tow as early as the middle of March (in 1927 and not until April in 1926, 1928, and 1929); and fry of this size were taken throughout April, May, and June. (See Table 4 and fig. 39.) Pigfish, as shown elsewhere (p. 402), are only about 1.5 millimeters long at the time of hatching, but they attain a length of 2.0 to 2.5 millimeters within a few days. Therefore, it is evident from the catches of these small fry, entirely aside from the fact that the eggs, too, were taken over most of this period, that spawning may occur from about the middle of March to the end of June. However, the young were taken in March only one year (1927) out of four (1926–1929), and they did not appear to be particularly numerous until May during any one year, and the very small fry again were fewer, according to townet catches, toward the end of June. It may be concluded, therefore, as already shown in another section of this paper (p. 398) in regard to the collection of eggs, that while spawning may occur as early as the middle of March, and ends near the last of June, it takes place principally during May.

The young at first, as is usual among fishes, do not grow as rapidly as they do a month or two later. This fact is brought out clearly by the growth curve. (Fig. 39.) The largest young taken in May, for example, when they may have been slightly over 2 months old, were 28 millimeters long. A month later the largest young of the season were 84 millimeters in length, or nearly three times as long as a month earlier. This rapid rate of increase in length of the largest young of the season continues through July and August, and thereafter it appears to be much slower. The reduced rate of increase in length in the largest fish of the season is reflected in the curve based on the average lengths of all fish measured, although at this time (September) the smaller fish of the season apparently were growing rapidly. (See Fig. 39.)

TABLE 3.—*Length frequencies of 9,512 pigfish*

[Measurements to nearest millimeter, grouped in 5-millimeter intervals]

Total length	March	April	May	June	July	August	September	October	November
0–4	9	93	1,033	91	----	----	----	----	----
5–9	6	411	252	40	----	----	----	----	----
10–14	----	70	365	524	13	----	----	----	----
15–19	----	----	15	704	63	----	----	----	----
20–24	----	----	----	541	109	----	----	----	----
25–29	----	----	2	121	100	2	----	----	----
30–34	----	----	----	49	95	2	----	----	----
35–39	----	----	----	10	109	7	----	----	----
40–44	----	----	----	15	88	9	----	----	----
45–49	----	----	----	7	74	17	----	----	----
50–54	----	----	----	20	80	27	----	----	----
55–59	----	----	----	16	76	59	----	----	----
60–64	----	----	----	25	113	77	2	----	----
65–69	----	----	----	5	88	91	6	----	----
70–74	----	----	----	3	123	113	10	----	----
75–79	----	----	----	8	91	120	14	----	----
80–84	----	----	----	2	86	164	27	3	----
85–89	----	----	----	----	89	154	26	5	3
90–94	----	----	----	2	78	200	31	12	23
95–99	----	----	----	----	72	182	30	23	56
100–104	----	----	----	----	41	168	45	37	98
105–109	----	----	----	1	15	91	33	27	117
110–114	----	----	----	1	6	48	47	46	108
115–119	----	----	----	2	----	19	33	37	87
120–124	----	----	----	5	----	28	22	45	42
125–129	----	----	1	2	----	14	29	22	14
130–134	----	----	1	4	----	16	24	22	10
135–139	----	----	1	8	----	11	13	18	9
140–144	----	----	1	8	----	3	14	15	9
145–149	----	----	1	8	1	2	10	4	3
150–154	----	----	8	8	1	2	7	6	1
155–159	----	----	4	11	2	5	1	1	2
160–164	----	----	2	10	1	1	----	3	----
165–169	----	----	----	11	3	7	----	3	2
170–174	----	1	2	12	3	5	1	6	1
175–179	----	----	1	9	1	2	1	8	----
180–184	----	1	1	10	4	6	2	11	2
185–189	----	----	----	2	3	4	5	7	1
190–194	----	4	----	4	5	2	4	13	1
195–199	----	2	1	3	3	2	2	11	1
200–204	----	11	----	5	2	3	5	12	1
205–209	----	8	----	3	4	----	3	6	3
210–214	----	9	----	6	3	2	1	11	2
215–219	----	1	----	5	1	5	1	5	4
220–224	----	7	----	3	----	1	2	7	3
225–229	----	5	----	5	1	1	5	2	----
230–234	----	3	----	4	1	1	1	3	4
235–239	----	1	----	1	1	----	1	4	5
240–244	----	----	----	2	----	----	1	3	5
245–249	----	----	----	----	1	----	1	5	1
250–254	----	----	----	----	----	----	2	----	----
255–259	----	----	----	----	----	----	1	----	3
260–264	----	----	----	1	----	----	2	----	----

TABLE 4.—*Rate of growth of 9,011 pigfish during their first summer*

Month	Fish measured	Smallest	Largest	Average
		Milimeters	*Milimeters*	*Milimeters*
March	15	2.5	7.0	4.3
April	571	2.5	12.0	6.2
May	1,580	2.0	27.0	5.6
June	2,188	2.0	80.0	18.6
July	1,608	10.0	112.0	57.4
August	1,656	25.0	145.0	85.9
September	482	60.0	155.0	106.1
October	326	80.0	156.0	116.6
November	585	87.0	157.0	[1] 108.7

[1] Decrease in average length explained in text.

The almost total cessation of growth indicated in the graph (fig. 39) of the largest fish for October and November and a decrease in the average length of all fish measured in November, while the smallest fish apparently were still growing rather rapidly, seems to require an explanation. The number of fish taken and measured during September, October, and November is not large (see Table 4), yet the catches are believed to represent fairly accurately samples of the fish present. In other words, the methods of collecting, mostly with the otter trawl, did not differ from those used the previous months and are believed to have been successful in taking representative samples. It has been shown that the larger fish appear to leave the local waters earlier than the smaller and younger fish. Since fewer and fewer large fish appeared in the catches, it would seem as if the earlier exodus of the larger fishes extended down to the O class and that the larger fish of the season were migrating in October and particularly in November, whereas the smaller ones remained in the shallow waters somewhat later. These migrations appear to explain why the growth curve (fig. 39) shows virtually no increase in the length of the largest fish taken during October and November. They also explain the decrease in the average length of all fish taken, from 116.6 millimeters in October to 108.7 millimeters in November, even though the graph shows an increase in the length of the smallest fish of the O class from 80.0 millimeters in October to 87.0 millimeters in November.

According to the data presented herewith (Table 4 and fig. 39) the earlier and fastest growing young may reach a length as great as 157 millimeters (about 6¼ inches) during their first summer, whereas the later and smaller young of the same season apparently are only 87 millimeters (3½ inches) long. Growth does not appear to proceed rapidly after the fish withdraw from the local waters, as already pointed out, for the smallest individuals definitely assigned to the I class in June were only 105 millimeters long. The length of the largest representatives of the same year class at this time was not definitely determined, because of insufficient data. However, a frequency curve indicates it to be near 180 millimeters.

AGE AT SEXUAL MATURITY

The smallest sexually mature pigfish observed were from 8 to 8½ inches (200–215 mm.) in length. It may be concluded from this fact and the data presented in the preceding paragraph that the fish of the I class are too small to spawn, the largest being only about 7¼ inches in length in June, at the end of the spawning season; and it seems certain that sexual maturity is not reached until the fish are about 2 years old. This conclusion was arrived at by Taylor (1916, p. 321) also, who based his conclusion mainly on the study of scales. Taylor found a great diminution in number after the age of 2 years, and he believes that many of the fish may perish after the first spawning. According to this author, comparatively few pigfish reach an age of 3 years and very few 4 years.

FOOD

Young pigfish, 12 to 25 millimeters in length (smaller ones not examined), according to the contents of 14 stomachs, feed almost wholly on copepods supplemented occasionally by a few ostracods. Somewhat larger fish, ranging from 25 to 35 millimeters in length, as indicated by the contents of 29 stomachs, still feed chiefly on copepods and sparingly on ostracods. This diet is now strongly supplemented, however, by minute gastropods. When the fish attain a length of 40 to 100 millimeters, according to the contents of 55 stomachs, they feed on larger crustaceans, such as amphipods, small shrimp, and crabs; and they take larger gastropods, also bivalve mollusks; they add worms in considerable quantity and also a few small fish.

The diet does not change greatly after the fish reaches a length of 100 millimeters, although larger representatives of the classes of foods mentioned are taken. In the examination of 108 stomachs of adult fish, crustaceans, including principally amphipods, shrimps, and crabs, were found 78 times; mollusks, principally bivalves with razor clams in the majority, were found 63 times; worms, 36 times; and starfish, 9 times. The wormlike cordate, Balanoglossus, which scents the flesh and gives it an unpleasant flavor, as pointed out elsewhere, was found only once.

The foods eaten by the pigfish, after it attains a length of about 40 millimeters, occur largely on the bottom only. The fish may be classed, therefore, as a bottom feeder, which includes in its diet such burrowing forms as Balanoglossus (found once) and Upogebia (found six times). The forms eaten, exclusive of a few shrimp and fish, are not utilized commercially. Furthermore, the pigfish utilizes mostly foods not entering into the diet of many of the other common local food fishes; and, therefore, it does not appear to be an important competitor.

BAIRDIELLA CHRYSURA, Lacépède. White perch; sand perch

The white perch occurs in the shore waters from Massachusetts to Texas, and it is very abundant from New Jersey to North Carolina. Although a fish of good flavor, it is not of much commercial value because of its small size. The maximum length attained is about 9¼ inches, and the greatest weight is close to 6 ounces. Only the largest individuals, 7½ inches and over in length, are seen in the markets; and these constitute only a very small percentage of the catch, the rest frequently being wasted. The species is not marketed in sufficient abundance to be shipped separately, the small quantities that reach the markets being thrown in with "mixed fish." For this reason this white perch, which must not be confused with the other white perch, *Morone americana*, is not listed in the statistical records of the Bureau of Fisheries.

The white perch is present in the local waters throughout the year. It is most abundant during the summer and becomes scarce during the winter, particularly during cold snaps. The young, or smaller, individuals of this species, as in the spot and croaker (as pointed out in the sections of this paper dealing with those species) are the ones that remain in the shallow waters, whereas the large individuals are seldom seen during the winter.

SPAWNING

At Beaufort spawning takes place from near the end of April to the middle of July. In 1927, for example, the eggs were taken for the first time during the last week in April, and by the end of June they had become scarce. Kuntz (1914, p. 3) working at Beaufort in 1913 says, "The height of the spawning season of *Bairdiella chrysura* occurs during the last week of June and the first week of July." This has not been the case during the four seasons (1926–1929) over which our observations extend, for each year spawning was just about over by the end of June, as shown by the scarcity of gravid fish in the catches examined, by the scarcity of eggs in the tow, and by the absence of fry under 5 millimeters in length in our collections for the month of July. According to our data the most prolific spawning in the white perch takes place during the last half of May and early in June.

Welsh and Breder (1923, p. 171) state that in New Jersey this fish spawns in June, July, and August and the height of the spawning season is reached in June. Hildebrand and Schroeder (1928, p. 282), working with the fishes of Chesapeake Bay, found ripe fish, trawled in 12 fathoms of water off Crisfield, Md., as early as May 16, and many of the fish were spawned out by June 11. These authors make the general statement that in Chesapeake Bay spawning takes place "in the late spring and early summer."

During the height of the spawning season the eggs are very numerous in the vicinity of Beaufort and frequently may be taken in large numbers in surface nets. The eggs, as well as the fry, occur in collections made at this time within the harbor and adjacent estuaries and sounds, also along the outside shores and at collecting stations as far as 12 to 15 miles (beyond which collecting was not extended) off Beaufort Inlet, indicating that spawning takes place within the harbor, the estuaries and sounds, and also for some distance out at sea. The eggs are small, averaging only about 0.68 millimeter in diameter, and are produced in large numbers, as the nearly ripe ovaries are so large that they cause a very pronounced expansion of the abdominal walls. A female from Chesapeake Bay, only 140 millimeters (5.6 inches) long, contained approximately 52,800 eggs (Hildebrand and Schroeder, 1928, p. 28). Larger examples no doubt produce a correspondingly greater number.

DEVELOPMENT OF EGGS AND LARVÆ

The development of the eggs and larvæ is quite fully discussed by Kuntz (1914 pp. 4–13), to which the reader is referred for information on this subject. It is sufficient to state here that Doctor Kuntz's work has been checked by the present authors and found substantially correct. Because of the similarity of the eggs of the white perch and the pigfish and, furthermore, because their eggs often are taken together in towings (for the spawning periods overlap) the difference between the eggs of the two species are pointed out and discussed in that section of this paper dealing with the pigfish.

DISTRIBUTION OF YOUNG

The fry, like the eggs, occur within the harbor and adjacent waters and at sea off Beaufort Inlet as far out (12 to 15 miles) as the collecting was extended. According to the frequency of the fry in the towings, they are more numerous at sea than in the inside waters. Although the fry were taken at the surface, they appear to be on the bottom more commonly, for in an approximately equal number of hauls made with two 1-meter townets, hauled simultaneously at the surface and on the bottom, the fry occurred in 12 surface hauls and in 23 bottom ones. Furthermore, the bottom towings generally contained more specimens than the surface hauls.

Young white perch, like young pigfish, as stated elsewhere in this paper, are present in grassy areas within the harbor at an early age, or when a length of about

10 millimeters is attained. In these areas they remain throughout their first summer. Although the majority leave their first summer's habitat when cold weather comes, a few remain there throughout the winter.

GROWTH

In the present studies an effort was made to secure information, mainly, relative to the rate of growth of the white perch during its first year of life. However, older fish often were taken and such examples have been measured and are included in frequencies in Table 5. Table 6 and Figure 40 include only the data pertaining to the O class. Since this fish has a comparatively short spawning season, little if any overlapping occurs between the O class and the older fish during the first 9 or 10 months of life. It is comparatively easy, therefore, to follow the rate of growth of the young fish during that time.

Tables 5 and 6 show that the young of the white perch grow rapidly during the first several months of life. For example some of the individuals attained a length of 30 to 39 millimeters in June when only 2½ months old at the most. The average length for June for 1,642 specimens measured, however, is only 8.7 millimeters. This low average is due to the very large number of recently hatched fry, less than 5 millimeters long, which occur in the collections. In July, when the smallest fry taken were 9 millimeters and the largest fish 76 millimeters long, the average for 987 fish is 31.9 millimeters. In September the young secured range in size from 45 to 122 millimeters, and the average size for 559 specimens is 81 millimeters.

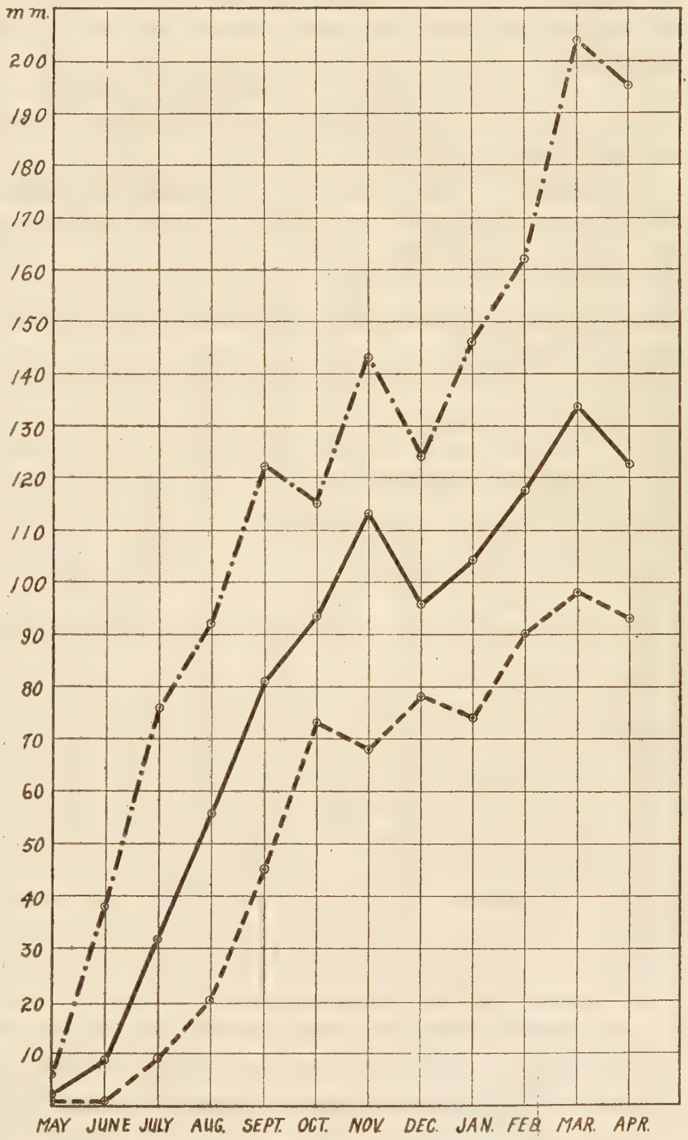

FIGURE 40.—Growth curve of young white perch, based on Table 6. Solid line, average of all fish; broken line, smallest fish; dot-and-dash line, largest fish

In February when the fish are only about 9 or 10 months old the range in size for 98 specimens is 90 to 162 millimeters (4 to 6.5 inches), and the average length is 117.5 millimeters (4.7 inches). The year classes are less distinct thereafter, as some overlapping probably takes place and, furthermore, our data are too meager to show the exact situation. In April, when the fish of this year class are still mostly under a year of age, the minimum size is 93 millimeters. There is some doubt relative to the maximum size but the average size is not far from 123 millimeters (5 inches), as the number that may have been wrongly assigned is too small to affect the average appreciably.

TABLE 5.—*Length frequencies of 6,347 white perch*

[Measurements to nearest millimeter, grouped in 5-millimeter groups]

Total length	May	June	July	August	September	October	November	December	January	February	March	April
0-4	966	918										
5-9	3	47	5									
10-14		223	48									
15-19		176	102									
20-24		223	146	2								
25-29		49	139	1								
30-34		5	148									
35-39		1	149	17								
40-44			91	32								
45-49			71	84	2							
50-54			56	101								
55-59			19	98	9							
60-64			9	71	26							
65-69			2	25	37		1					
70-74			1	20	78	2			1			
75-79			1	11	95	5		1				
80-84				5	110	5		3				
85-89	1			2	80	12		3				
90-94	1			1	42	15	1	5	3	3		2
95-99	1				34	11	2	11	11	8	1	6
100-104	3		1		14	6	13	6	14	12	14	14
105-109	3				8	9	5	1	12	9	21	9
110-114	4	1			13	2	4	1	10	17	35	14
115-119	1	1	2		8	1	9		8	5	40	11
120-124	1	1	7		3		4	1	4	15	38	1
125-129	4	2	3				2		5	6	40	2
130-134	1	1	29	2			3			9	15	1
135-139			31	2	3		3		1	6	5	2
140-144			60	4	4		2		2	4	3	
145-149				1	5	4			1	1		2
150-154	1		42		14	15	2			2		2
155-159	5		110	1	20	22	1			1	1	
160-164	3	2	72		10	53	3			1	3	1
165-169		2	69	3	6	35	3				3	2
170-174	1		3	2	7	34	4				5	1
175-179	1	1	99		1	27	2		1			2
180-184	1	1	62	3	2	24	2				3	1
185-189			20			14	1			1	1	4
190-194			18			10	4				1	1
195-199	1					6	2				1	1
200-204	1		4	2		3	1		1		2	
205-209			1			2	1				1	
210-214		1	2			5	1					
215-219							1					
220-224			1			1						
225-229							1					

TABLE 6.—*Monthly summaries of length measurements of 5,285 white perch during the first year of life*

Month	Fish measured	Smallest	Largest	Average	Month	Fish measured	Smallest	Largest	Average
		Millimeter	*Millimeter*	*Millimeter*			*Millimeter*	*Millimeter*	*Millimeter*
May	969	1	6	2.4	November	49	68	143	113.0
June	1,642	1	38	8.7	December	32	78	124	95.6
July	987	9	76	31.9	January	72	74	146	109.1
August	500	20	92	55.8	February	98	90	162	117.5
September	559	45	122	81.0	March	233	98	204	123.8
October	68	73	115	93.2	April	76	93	195	122.6

The data presented in the foregoing paragraph and in Tables 5 and 6 indicate that many white perch grow amply large to be sexually mature when 1 year of age, as gravid fish only 130 to 140 millimeters (about 5½ inches) in length are common, particularly during the latter part of the spawning season. It is not known, however, that these fish, although of ample size, actually spawn when only about 1 year old. The majority of the fish no doubt are too small to spawn at a year of age and quite certainly do not reproduce before they are 2 years old.

Welsh and Breder (1923, p. 174), working with fish from Beaufort and Chesapeake Bay, arrived at about the same conclusion relative to the rate of growth during the first summer, stating that a length of "6 to 14 centimeters (2½ to 5½ inches)" is attained by the first winter. These authors state, furthermore, "The first spawning occurs in the third season when the fish are 2 years old and between 15 and 21 centimeters in length (6 to 8¼ inches)." From scale studies these authors conclude, "After the first spawning growth is slow, the largest fish of which scales were examined having reached a length of 23 centimeters (9 inches) at the age of 6 years."

Hildebrand and Schroeder (1928, p. 281), working with fish from Chesapeake Bay, indicate a somewhat slower rate of growth than the data of the present investigation show for Beaufort fish. In September, for example, the range for Chesapeake Bay fish is from 40 to 109 millimeters, whereas the range for Beaufort fish is 45 to 122 millimeters. In November the range in size for Chesapeake Bay fish is given as extending from 76 to 117, while the range for Beaufort examples is 90 to 143 millimeters (one specimen taken 68 millimeters long). It is quite probable, therefore, that the rate of growth, as expected, is a little faster at Beaufort, the more southern locality, than in Chesapeake Bay.

FOOD AND FEEDING HABITS

The white perch with its terminal and slightly oblique mouth is not marked as a bottom feeder to the same extent as the croaker. However, it is shown on a preceding page that the fry were taken nearly twice as frequently and more abundantly on the bottom than at the surface. It is to be expected, therefore, that many although not all the forms constituting the food are bottom forms.

Small white perch, 7 to 20 millimeters long (smaller ones were not examined), as shown by the stomach contents of 30 specimens, feed chiefly on copepods, supplemented by ostracods, a few amphipods, cladocera, and an occasional Mysis and chætopod. Somewhat larger fish, 25 to 50 millimeters long, according to the contents of 64 stomachs, feed sparingly on copepods, ostracods, isopods, and more abundantly on somewhat larger crustaceans, including Mysis, small shrimp, and crabs. Also a few chætopods and mollusks were found. Examples 50 to 80 millimeters long (15 stomachs examined) had fed very largely on Mysis, shrimp, Gammarus, and chætopods. The diet of the last-mentioned group of young does not differ greatly from that of adult fish of which 20 specimens were examined, the only difference being that the adults had included a few fish (anchovies) in their diet.

Welsh and Breder (1923, p. 174) list the following forms found in 21 specimens taken at Cape Charles, Va., ranging in standard length from 60 to 82 millimeters: Schizopods, isopods, amphipods, polychæte worms, fish, and unidentified crustaceans. Hildebrand and Schroeder (1928, p. 280) say, "The food of this fish in Chesapeake Bay, as shown by the stomach contents of 100 specimens examined, consists very largely of small and minute crustaceans. Foods of much less importance are annelids and fish. Only two individuals of the entire lot examined had fed on fish."

It may be concluded from these studies of the food that the white perch feeds largely on the bottom, that it is strictly carnivorous, and that small to medium-sized crustaceans, frequently substituted by worms, constitute the chief foods eaten. It is evident also that this species is not a serious enemy of other fishes nor of commercially utilized crustaceans. On the other hand, the white perch not infrequently occurs in the food of such important commercial species as the weakfishes and flounders.

LEIOSTOMUS XANTHURUS (Lacépède). Spot

The spot is known from Massachusetts to Texas, and it is of sufficient commercial importance to be listed separately in the statistical reports of the United States Bureau of Fisheries from all the border States from New York to Louisiana. At Woods Hole, Mass., the northernmost limit of its range, Smith (1898, p. 101) found it only in the fall, when it was common, and all specimens taken were about 6 inches long. Fish of this size probably are young ones that visit these northern waters for a short period of time only. Pearson (1929, p. 210) reports the spot as common on the coast of Texas where it has little commercial value because it does not attain a sufficiently large size. This author states that fish as large as 9.8 inches are taken only occasionally and when spot are marketed they are thrown in with the mixed fish. The States producing spots in large quantities, according to the latest statistics available, are New Jersey (1,217,704 pounds in 1926), Virginia (1,768,206 pounds in 1925), and North Carolina (1,959,252 pounds in 1927).

The maximum size recorded for the spot appears to be a Chesapeake Bay record of 13⅝ inches and a weight of 22 ounces. In the vicinity of Beaufort the usual size of adults seen in the markets is around 10 inches. Such fish weigh close to one-half pound each. This fish, like the croaker and the squeteagues, apparently grows larger in the more northern parts of its range than it does farther south. Reference already has been made to Pearson's statement (loc. cit.) that the spot, although a regular resident and common on the coast of Texas, does not attain a sufficiently large size there to be of much commercial value. According to observations by the senior author the average size of the fish in commercial catches at Beaufort, N. C., is somewhat smaller than at Norfolk, Va. A similar discrepancy in size appears to prevail in the croakers and also in the weakfishes. The reason or reasons for an average decrease in size in the more southern waters of these sciænids is not known.

The spot is taken in small commercial quantities in the local waters throughout the summer, but the principal catches are made in the fall (October and November), when the large fish school. From November 4 to 7, 1914, for example, large schools appeared on Beaufort Bar and the fish were taken in schooner loads with purse seines. This method of catching food fishes is now forbidden by law, and locally the fish are caught mostly with drag seines and to a limited extent with sink nets; that is, with gill nets weighted and sunk to the bottom in the deeper waters.

The individuals in any one school generally are of rather uniform size. For example, the greatest range in size found in a catch consisting of several hundred fish, all taken in one haul with an otter trawl, was from 9¼ to 10½ inches.

The young spots—that is, those of the O and I classes—are present in the shallower waters throughout the winter, but the larger ones are seen rarely. During cold snaps that last long enough to cause a considerable drop in the water temperature the I class, too, become scarce in the harbor and estuaries. At other times during the winter they often may be taken in considerable numbers in the deeper channels within these waters, and more sparingly on grassy flats. These young spots, and frequently larger ones, are common off Beaufort Inlet during the winter. In fact, the larger ones that remain there, although rather small, often are caught with sink nets and marketed during the winter, when more choice fish are scarce.

In January, 1927, the water temperature at the laboratory pier, taken daily at 5 p. m. dropped as low as 5° C. on the 9th day of the month, and it remained there until the 14th when it came up to 9° C. On the morning of the 14th, the last day of the cold spell, many spots of the I class became numb and drifted ashore on Pivers Island and elsewhere in the vicinity which appears to show that they are unable to endure a very low temperature, 5° C. probably being close to lethal. It was not noticed that the young of the new year class suffered a similar mortality. However, as these fish were still quite small when the cold snap occurred, even a considerable mortality might have escaped notice. It is the opinion of the writers, though, that the recently hatched young are less sensitive to the cold than the older fish, as the former have been taken in large numbers in the harbor in an apparently active condition during cold snaps when larger spots had become scarce in the shallow waters.

It is evident from the foregoing remarks that adult spots, at least, make definite migrations. It is still an unanswered question, however, where the schools of large spots that appear in the inshore waters during the fall come from. It is true that small quantities of large spots are taken within the shallow waters during the summer, but the number is so small that it seems entirely unreasonable that they could form the large schools which appear suddenly in the fall and which are caught in large quantities. One is almost obliged to conclude that these fish come from the sea. If that were true, what would be the purpose of the migration? This is difficult to answer, especially as it is a migration of short duration and, as stated elsewhere, it evidently is not definitely a spawning migration, for spawning does not appear to take place within the sounds and harbor. A limited outward movement of the smaller and younger fish (I class) is indicated also. That the latter, at least, do not go far is shown by their quick return, for they reoccupy the harbor and estuaries between cold snaps. The accompanying length frequencies in Table 7 appear to show that some of the larger individuals of the O class probably move away from the shallower water for the winter along with the older and larger fish. This subject will receive further consideration under the subhead Growth.

That the adult fish do not go far after leaving the shallow inshore waters seems to be shown by the presence throughout the winter of numerous very small fry near the outer shores and also within the harbor and estuaries, as shown subsequently. Under the discussion on "spawning" it is shown, furthermore, that the principal spawning quite certainly takes place after nearly all the adult fish have left the shallow waters. It is deduced from these facts that the adult fish spawn only a short distance offshore. If this were not true it would seem highly improbable that the very small and comparatively helpless fry, only a few millimeters in length, would be common in the inshore waters. Since spawning appears to take place during most of the winter (p. 418), the indications are that the winter home of the adult spot is only a short distance offshore.

SPAWNING

The eggs of the spot, if taken, were not recognized. Numerous males with running milt were seen, but no females ripe enough for stripping were found. If the eggs were taken in the tow, which seems to us unlikely, they were not recognized.

During four successive years an effort was made to secure the eggs by confining gravid fish in tanks. The overflow was screened for eggs and the tanks were examined carefully daily for demersal eggs, also, but none were secured. One winter (1928–29), for example, a fine lot consisting of 18 large spots was held for several months in a tank in the terrapin brooder house at a warm temperature. Although these fish took food (cut fish) regularly and appeared to be in good condition they, like others, kept in tanks out of doors (until killed by the cold), failed to cast their eggs. Those that died during the winter were found to contain roe which appeared to be in about the same state of development as in specimens examined at the time of capture in October. Others which either died or were killed in May (long after the spawning season was over) still contained roe, but the eggs showed signs of disintegration. This, and other experiments, indicate that the spot will not cast its eggs in captivity under the conditions described unless by chance very ripe individuals should be confined which might spawn during the first or second day of captivity. At least, that was our experience with the pigfish and hogchoker from which we succeeded in getting the eggs during the first night and a few during the second night of captivity, but none thereafter.

The retention of the spawn in captivity under the conditions described is an interesting phenomenon, apparently well worthy of further study. The natural environment evidently must be more closely simulated than in the present experiments to induce the spot to carry out the spawning process. It was not determined what would happen eventually, whether the developing sexual products would be reabsorbed, discarded in an unnatural way, or whether their retention would result in death. It was noted only that an apparent disintegration of the eggs was taking place, as already stated, in those individuals retained the longest.

We find no record in the literature of spot eggs having been taken and since the fish failed to spawn in captivity and the eggs, if taken in the tow, were not recognized, their identity and manner of development remain unknown.

The time and duration of spawning, nevertheless, have been fairly accurately determined from the collections of young (larvæ) made during four seasons (1927, 1928, 1929, and 1930). The earliest young, a single specimen 3 millimeters long, was taken on November 12, 1927, at a station 12 miles WSW. of Cape Lookout. The larvæ did not reappear in the collections until early in December, when they became numerous and remained so for several months. The smallest larvæ taken during December, January, and February were, respectively, 1.5, 4, and 3 millimeters long. During the next three months—namely, March, April, and May—the smallest fry appearing in the collections were, respectively, 10, 7.7, and 11 millimeters in length. (Table 8.)

Larvæ only about 1.5 millimeters in length, without doubt, are hatched from a very small egg with a short period of incubation, probably not exceeding one week even during cold weather. This tentative conclusion is arrived at from our knowledge of the length of the incubation period of several other species having small eggs, especially the pigfish (*Orthopristis chrysopterus*) which begins spawning in April when the waters are still quite cold. This species has an egg from 0.65 to 0.8 millimeter in diameter and hatches a larva 1.5 millimeters in length. The newly hatched pigfish, therefore, is equal in length to the smallest spot larvæ secured and it seems plausible that the eggs of the two species are nearly of the same size. This supposition is supported further by the size of nearly mature eggs in the ovaries of both species. The incubation period of the pigfish, at the lowest temperatures that have prevailed during the spawning season, has never been observed to exceed three days. Therefore, one week would appear to be a liberal estimate of the duration of the incubation period of spot eggs.

If these deductions be approximately correct, it would follow, from the size and number of young in the collections, that at Beaufort some spawning may take place in November but that the principal spawning months are December and January, with diminished spawning activity in February.

Ova of several sizes are present in well-developed ovaries which suggests that the eggs probably are cast, a few at a time, over a period of several weeks. It was noticed, furthermore, that the sexual organs generally were further advanced in large individuals than in smaller ones in examinations made in October, which would indicate that the large fish spawn earlier than the smaller ones. This would lengthen the spawning season still further, causing it to extend, as already shown, probably during a part of November, throughout December and January, and possibly through at least a part of February.

The foregoing deductions in regard to the spawning period at Beaufort and the place of spawning are not out of accord with recently published statements for other localities. Hildebrand and Schroeder (1928, p. 274) state that spawning takes place (in the Chesapeake Bay vicinity) during late fall and probably during the winter and, apparently, at sea. That spawning occurs at sea was thought to be the case, because a large exodus from the bay of big fish with maturing roe takes place each year during late September and in October. It may be noted here also that, although winter collecting with townets and other fine-meshed gear was rather vigorously pursued during the investigation on Chesapeake Bay, the smallest spots taken were 15 millimeters long. It would seem, therefore, that the very small fry probably do not occur in the bay, in any considerable numbers, which is contrary to the situation in the vicinity of Beaufort where the larvæ are abundant in the inside waters, as already stated.

Pearson (1929, p. 204) states that the spot spawns in the Gulf of Mexico in close proximity to the mouths of the passes that lead into the partly inclosed coastal bays, and that spawning occurs from late in December until the last of March. The spawning season in Texas, therefore, would appear to be nearly identical with that at Beaufort. Mr. Pearson, apparently, did not take the eggs and presumably arrived at the conclusions given in regard to the place, time, and durations of spawning from the collection of young.

DESCRIPTIONS OF YOUNG

Specimens 1.5 millimeters long.—In fish of this small size the yolk sac appears to be completely absorbed. The mouth is quite well developed and very oblique; the body decreases in depth posteriorly, coming to a sharp point. The fin fold is present but plainly visible only on the posterior part of the tail. A dark membrane (peritoneum) lying above the air bladder (very distinct in slightly larger specimens) already is evident. Occasionally at this size there also is present a row of dark chromatophores along the ventral side, posterior to the vent, one on the middle of the side above the vent, and a few others on the head. The color markings become more definite in slightly larger fish. (Fig. 41.)

Specimens 2.8 millimeters long.—Many specimens of this size and larger ones are before the writers. The mouth is very oblique to nearly vertical; the body anteriorly, with the apparently loosely joined visceral mass, is rather deep, and posteriorly it is very slender, ending in a sharp point. In the dorsal profile there is a prominent swelling (hump) over the eyes and another at the nape. The hind gut is prominent and appears to be entirely free from the body distally. (In larger specimens it is plainly connected by membrane, and the membrane may have been broken in these larvæ.) A fin fold is present but rays are not yet evident in any of the fins. The dark membrane (peritoneum) lying dorsally of the abdominal cavity is plainly visible through the thin wall and is crescent shaped (conforming to the contour of the dorsal wall) when the fish is viewed from the side. An elongated dark chromatophore lies dorsally of the hind-gut. In addition, a row of dark chromatophores is present along the ventral edge of the entire caudal portion of the body.

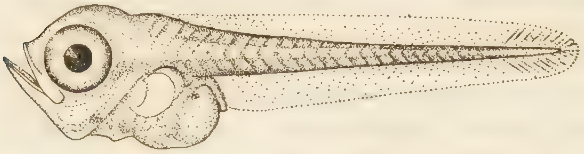
FIGURE 41.—*Leiostomus xanthurus.* From a specimen 1.7 millimeters long

Specimens 3.6 millimeters long.—The principal development that has taken place between this size and the smaller ones (2.8 millimeters) already described, is the appearance of rudiments of rays on the ventral side of the distal part of the tail. The fin developing here is destined to become the caudal fin. The mouth at this age (size) is less strongly oblique than in the younger individuals, already described. A dark chromatophore is present at the hinge (joint) of the mandible, situated slightly behind the vertical from middle of eye, and a few small indefinite dark specks are sprinkled over the head. (Fig. 42.)

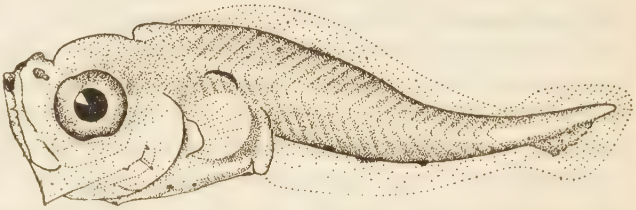
FIGURE 42.—*Leiostomus xanthurus.* From a specimen 3.2 millimeters long

Specimens 4.0 millimeters long.—The principal development that has taken place, since a length of 3.6 millimeters was attained, consists of the greater development of the caudal fin. The notochord, usually, although not always, is curved upward at this size giving the tail the appearance of being heterocercal. In some specimens, as in the one drawn, the notochord remains straight, however, the caudal rays being below it and directed obliquely downward. The dorsal profile of the head has become much more even in outline, the depressions and the humps having largely disappeared. The fin fold is prominent, and usually no thickening of the membranes in the regions somewhat later to be occupied by the dorsal and anal fins has taken place. (Fig. 43.)

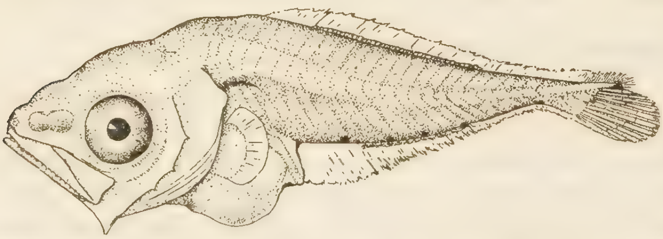
FIGURE 43.—*Leiostomus xanthurus.* From a specimen 4 millimeters long

Specimens 6.0 millimeters long.—At this size the caudal portion of the body has become proportionately much deeper and the break in the ventral outline between the body and tail is much less pronounced than in younger individuals. The caudal fin is fairly well formed and its base (oblique in smaller fish) now is in a vertical plane, the notochord being strongly curved and ending at the base of the upper rays. A thickening and a slight projection of tissues has taken place in the region that will be occupied by the base of the anal and for a part of the base of the dorsal also. The bases of a part of the rays are becoming evident as pale and slightly protruding areas. No changes in color worthy of note have taken place since a length of 3.6 millimeters was attained.

Specimens 7.0 millimeters long.—At this size the anal fin occasionally is well enough developed to show the anal rays, or at least the articulations between the rays and the interhæmal spines generally are evident, appearing as somewhat elongate, rectangular pale areas, surrounded by a dark line. (The prominence of these markings appears to depend partly on preservation, as in some lots they are uniformly more distinct than in others.) It often is possible to get a fairly accurate count of the rays from these sutures even though the rays themselves are not evident. The dorsal fin generally is somewhat less definitely developed than the anal, and the spinous portion is still missing. The pectoral and ventral fins are just becoming visible, being short and without definite rays. The hind gut no longer projects prominently. However, a large space, with only a semitransparent membrane, remains between the vent and the origin of the anal. This area exceeds in length the diameter of the eye. The notochord is still evident and its extremity is visible in the fin membrane above the base of the uppermost ray of the caudal. The spinal column, too, is visible on the median line of the side at the base of the caudal. Pigmentation now consists of a dark spot at the articulation of the mandible; the dark peritoneum above the viscera (very evident in smaller specimens) is still rather faintly visible through the abdominal wall; a dark chromatophore remains at a point slightly in advance of the origin of the anal; other pigment spots are situated along the ventral edge, as in smaller specimens. (Fig. 44.)

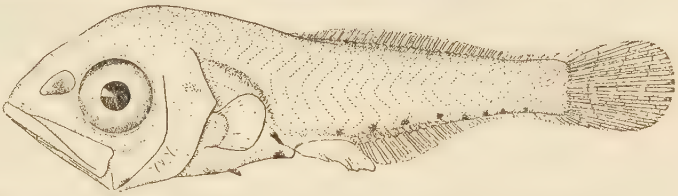

FIGURE 44.—*Leiostomus xanthurus.* From a specimen 7 millimeters long

Specimens 10.0 millimeters long.—The anal spines and rays are quite fully developed, and an accurate count can be made under proper magnification and illumination. The soft dorsal is well developed, except posteriorly where the rays are very short and indefinite. Although a variation in the progress of development exists, the base of the spinous dorsal usually is evident only as a thickened membrane and generally no spines, as yet, are evident. The middle rays (about 10) of the caudal fin are all of nearly the same length, making the posterior margin of the fin straight. (In smaller specimens the margin is round.) The pectorals and ventrals are short but have definitely differentiated rays. The mouth is much less oblique than it is in smaller specimens and it is slightly inferior, approaching in both respects the position it has in the adult. The heterocercal character of the tail—that is, the upward bend in the notochord, prominent in somewhat smaller specimens—scarcely is discernible. Pigmentation has undergone no changes worthy of note. (Fig. 45.)

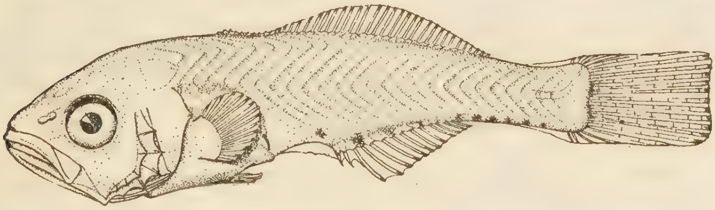

FIGURE 45.—*Leiostomus xanthurus.* From a specimen 11 millimeters long

Specimens 15.0 millimeters long.—The changes in development in fish of this length and those 10 millimeters long are not pronounced. The first dorsal now has most of the spines (anterior ones) developed. They are very slender and become short and usually indistinct, or are missing, posteriorly, and generally no definite count can, as yet, be made. The heterocercal character of the tail has disappeared completely. The membrane between the vent and the origin of the anal, previously described, has become narrower, and the almost vacant space is gradually becoming smaller. The pigmentation remains essentially the same as described for 7.0 millimeter specimens, except that the black peritoneum no longer is visible through the body wall and a few dark markings are present on the base of the caudal. (Fig. 46.)

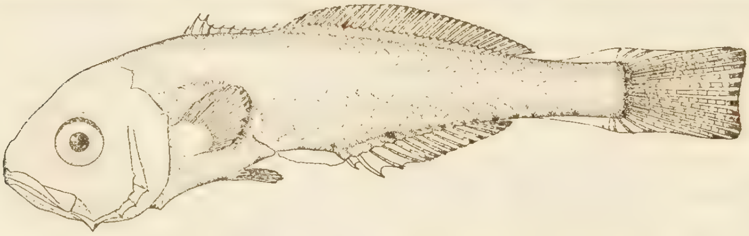

FIGURE 46.—*Leiostomus xanthurus*. From a specimen 15 millimeters long

Specimens 20.0 millimeters long.—The body at this age (size) continues to be more slender than in the adult, the greatest depth being contained in the length to base of caudal about 3.8 times (adults about 2.6). The dorsal outline is quite convex but not nearly as much so as in the adult. All the fins, including the spinous dorsal are well developed, and it is possible to enumerate for the first time all the dorsal spines. The posterior margin of the caudal fin at this size is distinctly concave. The fish is still without color, except for the few pigment spots described for smaller individuals. At this age, as well as in much younger individuals, there are distinct spines on the preopercular bones, which disappear later. (Fig. 47.)

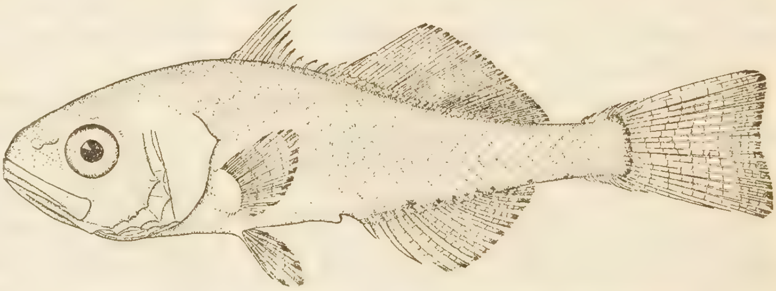

FIGURE 47.—*Leiostomus xanthurus*. From a specimen 20 millimeters long

Specimens 25.0 millimeters long.—No pronounced changes in the development occur between a length of 20 and 25 millimeters. The body has become proportionately deeper, and the back is higher. The mouth is less oblique and somewhat more inferior. A vacant area between the vent and the origin of the anal, previously occupied only by a semitransparent membrane, is now filled in with heavier tissues, leaving only a slight concavity. The principal development between a length of 20 and 25 millimeters is that of pigmentation. A dark chromatophore previously situated on the side, a little in advance of the origin of the anal, has disappeared. The rest of the dark spots, extending along the ventral edge from the origin of the anal to the caudal are still present, as in much smaller individuals. A row of vertically elongate dark spots on the base of the caudal fin has become more pronounced, and new chromatophores have appeared about the mouth, on the head, and a row of widely spaced ones along the upper edge of the back. A very small chromatophore is present on the median line of the side of the caudal peduncle, slightly in advance of base of caudal, and a few dark points of even smaller size lie in the same plane forward of it. A dark spot situated about at the "hinge" of the mandible, described for very young (3.6 millimeters), still persists. There is also a prominent chromatophore on the median line slightly behind the isthmus and another at the base of each ventral. Some variation from the pattern described has been noticed, as well as a considerable difference in the intensity of the markings. (Fig. 47.)

Specimens 30.0 millimeters long.—No scales are visible in fish 25 millimeters long. However, when a length of 30 millimeters is attained scales are evident nearly everywhere, the rows forming first and being furthest developed on the sides of the abdomen. None of the scales as yet appear to overlap or have free margins. The spines attached to the preopercular bones, described for smaller specimens, have completely disappeared or more usually are visible within the membrane bone of the preopercle, and frequently their tips extend slightly beyond the preopercular margin. The lateral line is largely developed. Pigmentation proceeds rapidly while the fish grows from 25 to 30 millimeters in length. At the larger size the fish is silvery on the lower part of the sides of head and body, and (in alcohol) it is brownish on the back and upper parts of the sides. The body nearly everywhere is marked with dark chromatophores which extend on all the fins, exclusive of the ventrals. In most specimens 30 millimeters long a row of dark blotches is evident along the median line of the side, and faint saddlelike blotches sometimes may be seen on the back. (Fig. 48.)

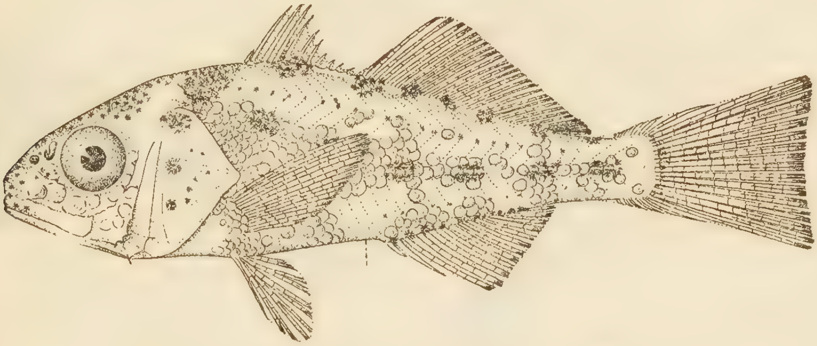

FIGURE 48.—*Leiostomus xanthurus.* From a specimen 30 millimeters long

Specimens 50.0 millimeters long.—At this size the fish has acquired essentially the form and the color of the adult. The snout is definitely blunt, and the mouth is horizontal and inferior. The back is decidedly elevated, and the lower outline is nearly straight. The body has become rather deep, the depth now being contained in the length to the base of the caudal about three times, whereas in the adults the depth is contained in the length about 2.6 times. Dark oblique bars (generally of a yellow or brassy shade in life) are present on the back, as in the adult, although less distinct. The dark spot at the shoulder, from which the species derives its common name, is faintly visible. In fact, the principal characters which distinguish this species from all other forms—namely, the comparatively short, compressed body, high back, short obtuse head, the small horizontal mouth, the rather long anal fin, the concave margin of the caudal fin, the oblique bars, and the dark shoulder spot—are all fairly well developed at this size, and the fish is readily identified with the adult. (Fig. 49.)

COMPARISON OF YOUNG SPOTS AND CROAKERS

Young spots and croakers are very similar and until a length of about 10.0 millimeters is reached are difficult to distinguish. A comparison of the larvæ of the two species, therefore, has been prepared and is presented under the discussion of the croaker (p. 439). The differences between the very young of the spot and croaker unfortunately are largely of degree only; that is, one has a slightly larger eye and a deeper tail than the other, etc., and are difficult to apply unless specimens of like sizes of both species are available for comparison.

DISTRIBUTION OF YOUNG

The fry occur in about equal abundance in towings made in Beaufort Harbor and in those made off Beaufort Inlet, some of the stations being as much as 12 to 15 miles offshore. The fry were taken in the bottom tow 103 times and in the surface tow 50 times, indicating that the larvæ may be present at any depth but that they occur more frequently at the bottom than at the surface.

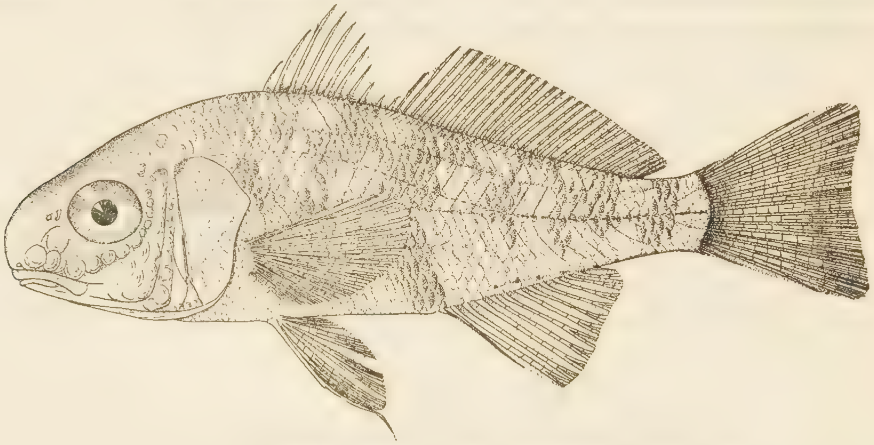

FIGURE 49.—*Leiostomus xanthurus.* From a specimen 46 millimeters long

From February to April schools of young fish often are seen along the shores of Pivers Island, the favorite places being protected coves around stone breakwaters and jetties. Somewhat later, fish an inch and above in length become numerous in shallow water in places where an abundance of vegetation is present. In such places young fish may be taken with dragnets throughout the summer and far into the winter. In other words, young spots remain in this environment until at least a year old. Young spots also ascend brackish water ditches to fresh water during the spring and early summer. Fish found in such an environment generally are larger than those found among vegetation in saltier water. Fish taken in the deeper channels in Beaufort Harbor during the winter months, too, are larger than those commonly found in the shallow, "grassy" waters. Spots ranging from about 3 to 6 inches in length, presumably mostly still in their first year, are abundant off Beaufort Inlet during the fall and early winter, and many are taken in shrimp trawls.

GROWTH

In the present studies a special effort was made to acquire information relative to the growth of the spot during its first year. In the course of the work considerable information was gained, however, in regard to its growth during the first six months or so of its second year. No special effort was made to secure the older fish, but when taken along with the younger fish they were measured and the data are included in Table 7. Table 8 and Figure 50 include the measurements of young fish only; that is, until an age of about 18 or 19 months is attained, as determined from Table 7.

It is evident from Table 7 that it is a little difficult to separate the largest representatives of the O class after they attain an age of 6 or 7 months from the I class, partly because the two classes intergrade in size and partly because insufficient measurements of the larger fish are available. However, the average size given for the various months in Table 8 and Figure 50 must be nearly correct, as the larger fish, which may have been wrongly assigned as to the year class, are so few in number that the average could not have been affected greatly because of the error involved. While the maximum sizes given for the O class may be somewhat in error, it is believed, nevertheless, that the average lengths shown for this year class are very nearly correct.

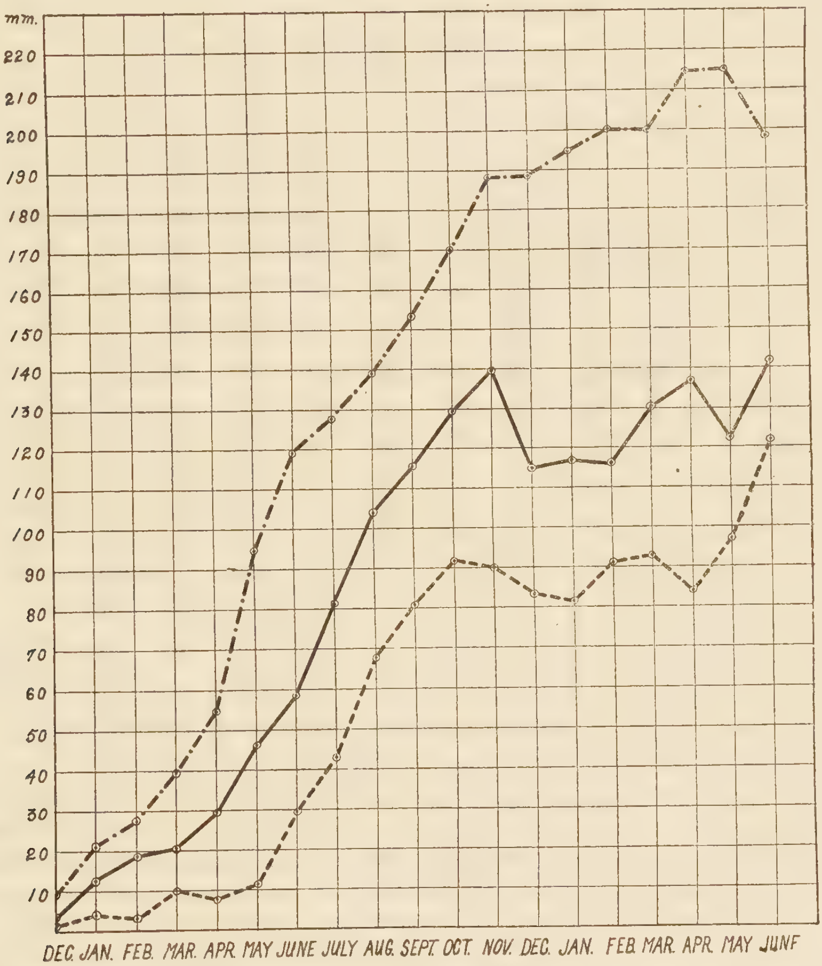

FIGURE 50.—Growth of spot (*Leiostomus xanthurus*) during first year or so of life; also illustrating size of fish of same year class which spend their second winter in shallow water. Reason for decrease in average length explained in text. Solid line, average size; dot-and-dash line, maximum size; broken line, minimum size. (Graph based on Table 18)

TABLE 7.—*Length frequencies of 20,082 spots*

[Measurements to nearest millimeter, grouped in 5-millimeter intervals]

Total length	December	January	February	March	April	May	June	July	August	September	October	November
0-4	102	3	12	----	----	----	----	----	----	----	----	----
5-9	20	64	31	----	5	----	----	----	----	----	----	----
10-14	----	64	44	73	7	7	----	----	----	----	----	----
15-19	----	94	180	1,179	16	24	----	----	----	----	----	----
20-24	----	3	163	1,081	70	36	----	----	----	----	----	----
25-29	----	----	5	313	130	104	1	----	----	----	----	----
30-34	----	----	----	53	190	172	38	----	----	----	----	----
35-39	----	----	----	4	74	89	68	----	----	----	----	----
40-44	----	----	----	----	30	76	116	1	----	----	----	----
45-49	----	----	----	----	3	84	183	4	----	----	----	----
50-54	----	----	----	----	1	97	194	5	----	----	----	----
55-59	----	----	----	----	----	100	59	29	----	----	----	----
60-64	----	----	----	----	----	84	48	63	----	----	----	----
65-69	----	----	----	----	----	63	28	32	1	----	----	----
70-74	----	----	----	----	----	37	44	65	14	----	----	----
75-79	----	----	----	----	----	25	51	77	21	----	----	----
80-84	1	2	----	----	1	16	39	86	34	2	----	----
85-89	8	10	----	----	4	2	36	85	41	4	----	----
90-94	30	93	4	----	14	4	26	53	54	28	3	5
95-99	88	261	17	1	31	6	16	49	63	36	8	4
100-104	259	583	124	16	54	12	10	39	88	48	19	8
105-109	360	625	312	36	67	29	15	26	86	72	50	11
110-114	534	676	457	71	56	52	6	21	67	59	45	41
115-119	358	509	303	99	69	53	5	15	74	83	41	62
120-124	219	446	186	87	66	51	11	11	48	74	41	115
125-129	121	302	84	77	54	41	26	3	30	57	47	119
130-134	101	241	65	82	60	32	29	2	12	35	58	157
135-139	81	190	29	46	44	29	28	4	8	19	56	110
140-144	52	150	25	38	31	16	37	7	7	14	25	110
145-149	42	93	13	28	25	10	22	9	5	5	8	67
150-154	27	50	16	22	35	7	22	4	4	7	23	79
155-159	24	25	5	14	28	3	8	1	----	3	14	59
160-164	10	18	5	25	32	7	12	3	7	9	22	58
165-169	6	14	4	17	48	3	5	2	----	13	13	29
170-174	1	10	4	7	35	6	4	----	3	8	5	31
175-179	2	4	1	10	29	7	1	2	3	3	5	24
180-184	3	3	5	7	28	2	3	2	2	4	4	34
185-189	2	3	1	3	20	4	----	2	----	1	4	6
190-194	----	1	----	1	26	4	----	1	----	1	3	8
195-199	----	1	1	2	19	----	2	----	1	----	1	3
200-204	1	----	2	1	17	----	----	1	2	----	2	1
205-209	----	----	----	----	4	----	----	1	1	3	1	1
210-214	----	----	1	----	4	1	----	----	----	----	----	2
215-219	----	----	----	----	5	1	----	2	1	----	----	----
220-224	----	----	----	----	----	----	----	2	----	----	----	----
225-229	----	----	----	----	----	1	----	----	----	1	----	----
230-234	----	----	----	----	1	----	----	----	----	1	2	1
235-239	----	----	----	----	----	----	----	----	----	----	1	----
240-244	----	----	----	----	----	----	----	----	----	----	----	----
245-249	----	----	----	----	----	----	----	----	----	----	----	----
250-254	----	----	----	----	----	----	----	----	----	----	3	----
255-259	----	----	----	----	----	----	----	----	----	----	1	----
260-264	----	----	----	----	----	----	----	----	----	----	2	1
265-269	----	----	----	----	----	----	----	----	----	----	1	----

TABLE 8.—*Monthly summaries of length measurements of spots during their first 18 or 19 months*

Month	O class				I class			
	Number of fish	Smallest	Largest	Average	Number of fish	Smallest	Largest	Average
		Millimeter	*Millimeter*	*Millimeter*		*Millimeter*	*Millimeter*	*Millimeter*
December	122	1.5	9.2	3.7	2,329	84	188	[1] 115.6
January	228	4	21	12.6	4,310	82	195	[1] 116.9
February	435	3	27	18.5	1,660	91	200	[1] 115.8
March	2,703	10	39	20.3	690	93	200	130.4
April	526	7.5	54	29.8	875	84	214	137.0
May	1,020	11	94	45.8	376	97	215	123.0
June	983	29	119	57.7	210	122	198	142.6
July	664	43	127	81.4	----	----	----	----
August	641	67	139	104.6	----	----	----	----
September	543	81	153	115.5	----	----	----	----
October	478	92	170	129.5	----	----	----	----
November	1,140	90	188	139.3	----	----	----	----

[1] Reason for decrease in average length in December explained in text.

It seems rather certain, as pointed out elsewhere (p. 397), that many of the larger representatives of the O class (becoming the I class during the winter) leave the shallow waters along with the adult fish upon the approach of cold weather. This is thought to be the case because the average size of the young fish, now the I class, taken during the winter months is smaller than it was in October and November. For example, the average size of 1,140 fish of the O class taken in November is 139.3 millimeters, while the average for 2,329 fish of the same year class taken during December is only 115.7. The average size of 4,310 fish of the same year class taken in January is 116.9 and for 1,660 fish taken in February it is 115.8. Such a decrease in size, since the methods and places of collection did not change and occurred each winter from 1927–28 to 1929–30, inclusive, apparently can be explained only on the basis that the larger fish were not properly represented (although some large ones were present) on the collecting grounds.

An increase in the average size occurs in March, as shown by Table 8, but it is not until June when the November average is exceeded. While the data are not sufficient for a definite conclusion, they do indicate that many of the larger representatives of the I class probably fail to reoccupy the shallower waters, where the collections were made, after their early winter departure.

Small fish, presumably of the O class, are reported from Chesapeake Bay for December and January by Hildebrand and Schroeder (1928, p. 273). The average size of these fish was notably smaller than that of specimens of the same year class taken in October and November. The authors came to the tentative conclusion that the fish taken in Chesapeake Bay during the winter probably were the "runts" of the last spawning season which had remained in the bay, while the larger representatives of the same year class had departed. This contention certainly is strongly supported by the behavior of the fish at Beaufort, as shown by the present investigation.

Growth appears to progress fairly rapidly in young spots. The largest fish taken in January, when probably only a little more than a month old, was 21 millimeters long and many examples exceeded a length of 15 millimeters. The largest specimen of the recently hatched fish caught in February was 27 millimeters and many had reached a length of over 20 millimeters. In March the largest fish was 39 millimeters long and numerous specimens had attained a length of over 25 millimeters. The average length of the fish of this year class taken during January, February, and March, as shown by comparatively large series of measurements was, respectively, 12.6, 18.5, and 20.3 millimeters. These averages were held down by the continued presence of very small fish, presumably resulting from recent hatchings, for in January and during the early part of February many larvæ under 10 millimeters in length appeared in the collections. However, none under that length was taken in March, and thereafter the average size of the specimens increased rapidly.

Although the growth of young spots during their first several months, regardless of the winter weather, is fairly fast, development proceeds even more rapidly in the spring when the water becomes warmer, for in April the average length of 526 fish was 29.8 millimeters and in May for 1,020 fish the average length had increased to 45.8 millimeters. This rapid rate of increase in length continues until September, when the fish, according to measurements of 543 fish, had attained an average length of 115.5 millimeters. It is a well-known fact, of course, that when fish attain a fairly large size the rate of increase in length decreases, and this is what takes place in the spot when an age of about 8 to 10 months and a length of about 115 millimeters is reached. The spot thereafter increases in depth and plumpness; and the gain in weight very probably is proportionately greater, even though the increase in length is smaller, than it was earlier in life.

The average size of the spot at the age of about 1 year, as shown by Table 8 and Figure 50, is 139.3 millimeters (5.6 inches) and the maximum size probably is about 188 millimeters (7.5 inches). Owing to the apparent departure of many of the larger spot of this year class from the local shallow waters, as shown by the decrease in the average length of specimens taken (Table 8) and pointed out elsewhere (pp. 416, 417), the rate of growth of the spot after an age of about 1 year is attained can not be followed now at Beaufort and must remain unknown until the winter home of these larger fish is found, together with means and methods of taking them there. The data accumulated for the I class are included in the graph (fig. 50), not because they show rate of growth but merely to illustrate the decrease in average length which presumably is due to the absence of many of the larger fish of this year class in the harbors, estuaries, and inshore waters of the vicinity where the collections were made.

Welsh and Breder (1923, p. 179) state that growth during the winter months, even in southern waters, appears to be retarded or altogether lacking. The authors state, furthermore, that "postlarval" examples taken in Florida between January and April showed no increase in length during this period. The authors do not state how numerous their collections were, and it is conceivable that their material might not have been entirely representative. The young fish assemble in schools (at Beaufort, at least) when a length of about 12 to 15 millimeters is attained. These schools appear to break up later when the fish are 25 millimeters or so in length. When schooled the fish may be taken in large numbers, but they might not be representative of the year class, because each school appears to consist of fish of nearly uniform size. It is necessary, therefore, to obtain samples from many different schools in order to secure the true range in size, as well as a true average length. Since we found a fairly rapid rate of growth of the fry during the winter months at Beaufort, we are inclined to believe that the samples secured in Florida by Welsh and Breder were faulty; that is, the collections did not include the true range in size and for that reason failed to show the rate of growth. Furthermore, Pearson (1929, p. 207) working in Texas found a range in length from April 17 to May 22 (1927) of 40 to 120 millimeters and an average length of 70 to 80 millimeters which indicates rapid winter growth and which considerably exceeds the rate of growth at Beaufort, for the range in size in our collections for May is 11 to 94 millimeters and the modal length is about 45 millimeters.

Welsh and Breder (loc. cit.), furthermore, state that a large series of 1-year-old fish taken at Fernandina, Fla., in December and March showed no increase in length during the period between observations. It is quite conceivable that at Fernandina, as at Beaufort, some of the larger fish withdraw from the shallower waters and that no growth was shown, because the collections were not representative of the year class. It may be pointed out also that very little winter growth is indicated by the rather meager data secured by Pearson (loc. cit.) in Texas. Possibly this, too, was due to the departure of the larger fish of the I class from the collecting grounds.

The rate of growth of the spot appears to be slightly more rapid in southern waters than in more northern ones. Welsh and Breder (1923, p. 178) estimate that the spot reaches a length of only 80 to 100 millimeters (3 to 4 inches) during its first year in New Jersey. Hildebrand and Schroeder (1928, p. 274) assign a modal length of about 125 millimeters (5 inches) to 1-year-old spots in Chesapeake Bay. The present investigation indicates that the average length attained at Beaufort at an age of 12 months is about 140 millimeters (5.6 inches). Welsh and Breder (loc. cit.) assign the same modal length, namely 140 millimeters (5.6 inches) to 1-year-old fish at Fernandina, Fla., and Pearson (1929, p. 209) indicates an average length of about 130 to 140 millimeters (5.1 to 5.6 inches) at 1 year of age for fish taken in Texas. The difference in the rate of growth of the spot during the first year, as shown by the information available, is not great for the different localities given, except for New Jersey.

No special effort was made during the present investigation to follow the rate of growth of the spot after the first 12 months of life, as already stated. Furthermore, it would be extremely difficult, if not impossible, to obtain reliable information on the growth of the older fish from length frequencies. Such work certainly would have to be supported by scale studies, and even then it would be difficult because of the migrations performed by the fish, as pointed out elsewhere.

Welsh and Breder (1923, p. 179) found it difficult to determine the age of spots by scale examinations, owing to the faintness of the winter rings. However, they estimated from such studies that 1-year-old spots in New Jersey are 3 to 4 inches; 2-year-old ones, 6¾ to 8¾ inches; and 3-year-old ones, 9½ to 11½ inches long. The largest example examined was 11¾ inches long, and the age indicated by the scales was 4½ years. Pearson (1929, p. 209) assigns a length of 7.4 to 8.2 inches to the fish at the end of their second year, and few older fish were observed.

The data in frequencies in Table 7 show that a considerable percentage of the fish of the I class reach a length of 190 to 200 millimeters (7½ to 8 inches) at Beaufort by April when about 16 or 17 months old. The data for this year class after that month are too meager to be significant but the indications, at least, are that many of the fish at the end of their second year exceed a length of 8 inches. It seems improbable, however, that the 2-year-old fish constitute the bulk of the schools of large fish taken locally in the fall of the year which generally range upward of 9½ inches in length. Such fish quite certainly are near the end of their third year or older.

AGE AT SEXUAL MATURITY AND THE SPAN OF LIFE

No spots less than 8 inches in length with developing or nearly mature roe were seen during the present investigation. The small, ripening fish contrary to the larger ones are not found in schools but are taken one or a few at a time. Hildebrand and Schroeder (1928, p. 274) examined 104 fish, ranging from 4½ to 10½ inches in length, taken at Ocean View, Va., in October, shortly prior to the spawning season, and found no fish less than 8½ inches in length with gonads in such a state of development that they would have spawned that year. Pearson (1929, p. 209) found some fish in Texas (where the spot does not grow large) only a little over 6½ inches in length in spawning condition. However, he concludes that these small fish were approaching an age of 2 years. It is evident also that Beaufort and Chesapeake Bay fishes do not reach sexual maturity at 1 year of age, for it has been shown in the preceding pages that few, if any, fish from these localities reach a length as great as 8 inches during their first year and that the average length attained is only about 5 to 5½ inches, whereas the minimum spawning size, as already shown, is 8 to 8½ inches.

The present writers, as stated elsewhere, did not make a special study of the age and growth of the spot after they are a year old, and they have no specific data to present which would show when sexual maturity is reached. However, the data in Table 7 show that a considerable percentage of the fish of the I class have reached a length as great as 190 to 200 millimeters (7.6 to 8 inches) in April. It seems certain that fish of this size will have grown amply large by the following December, January, or February to be spawning fish. It may be concluded, therefore, that at least some of the spots spawn at Beaufort when 2 years old.

Comparatively little is known of the duration of life of the spot, and the present authors have little to add. Welsh and Breder (1923, p. 179) took a spot in New Jersey 11¾ inches long which had attained an age, as shown by winter rings on the scales, of 4½ years, and they found many that were 3 years old. Pearson (1929, p. 209), on the other hand, found few fish in Texas over 2 years old; and he concludes, "* * * few fish reach an age of over 2 years in Texas coastal waters." The writers have reason to believe, as shown elsewhere (p. 429) that the bulk of the commercial catches made at Beaufort consists of fish not less than 3 years old, but they have no information relative to the greatest age that may be attained.

FOOD AND FEEDING HABITS

The small inferior mouth at once indicates that the spot is a bottom feeder and that it subsists on rather small objects. An examination of the stomach contents shows this to be the case. Published accounts (Breder and Welsh, 1923, p. 179, and Hildebrand and Schroeder, 1928, p. 272) show that this fish feeds very largely on small crustaceans, principally amphipods and ostracods, and also on minute mollusks, annelid worms, fish, and vegetable débris.

The published records, apparently, are based on fish that had attained a length of upward of 2 inches, and many of the specimens examined were adult. In the present investigation 135 stomachs of small specimens ranging from 15 to 100 millimeters (⅗ of an inch to 4 inches) in length were examined. The smallest specimens, or until a length of about 25 millimeters was attained, had fed wholly on small crustaceans, principally copepods with comparatively few ostracods. Thereafter, detrital material occurred in the stomachs in increasing abundance, apparently supplementing the previous diet which consisted of small crustaceans. After the detrital material appeared in the stomachs minute mollusks and annelid worms also were taken. In the detrital material, fragments or shreds of plants frequently were noticed and the relatively large amount of sand present—sometimes constituting fully 50 per cent of the contents—appears to be worthy of note.

The appearance of detritus in the stomachs when the fish has reached a length of about 25 millimeters, coincides quite accurately with the time when the schools of young spot, frequently seen during the winter and early spring in quiet coves, appear to break up and disappear. It is at this size, when the previously oblique terminal mouth has become inferior, as in the adult, that the fish is ready to begin feeding on the bottom and to subsist essentially on those foods that will furnish nourishment during the remainder of its life.

MICROPOGON UNDULATUS (Linnæus). Croaker; Hardhead

The croaker is known from Massachusetts to Texas and is of sufficient commercial importance to be listed separately in the statistical reports of the United States Bureau of Fisheries from all the border States from New York to Texas. In Massachusetts it is occasionally taken at Cape Cod (Welsh and Breder, 1923, p. 180), and in Texas it is common, but the size attained, according to Pearson (1929, p. 203), is so small (average about 8.6 inches) that the species has comparatively little commercial value. The States producing croakers in large quantities, as shown by the most recently published statistics of the United States Bureau of Fisheries, are New Jersey (2,455,867 pounds in 1926), Maryland (2,602,861 pounds in 1925), Virginia (22,649,295 pounds in 1925), and North Carolina (3,932,058 pounds in 1927). Other States producing considerable quantities, according to the United States Bureau of Fisheries statistics of 1927, are Florida (85,392 pounds), Louisiana (185,642 pounds), and Texas (104,098 pounds).

The maximum size attained by the croaker is about 20 inches, and a weight slightly in excess of 4 pounds (Hildebrand and Schroeder, 1928, p. 287). Most of the croakers marketed at Beaufort are small, belonging to a size known as "pinhead croakers" on Chesapeake Bay, ranging from about 7 to 10 inches in length. This is the usual size of the croakers taken in the vicinity of Beaufort in strictly salt water. Larger fish, with red fins, known locally as red-fin croakers, are taken in brackish to fresh water. In general, it may be stated that the croakers, as seen in the markets, run smaller in the vicinity of Beaufort than they do at Norfolk and other points on Chesapeake Bay. The decrease in the average size attained would appear to become more pronounced farther southward, as Pearson (loc. cit.) points out that the croaker has comparatively little value in Texas because of the small size attained. A somewhat similar decrease in size in the more southern parts of the range of the spot is pointed out in the section of this paper dealing with that species.

The croaker is taken at Beaufort virtually throughout the year. It disappears from the shallower waters where fishing operations are carried on during cold snaps, but it returns as soon as the temperature increases. Although this species is not plentiful during the winter and the average size of the individuals is small, they bring a fair price because of the scarcity of other fish at that season. The winter catches of croakers are of importance not only because they keep the local, as well as certain distant markets, supplied with fresh fish at a season when they are scarce, but they are of considerable aid to the fishermen and fish dealers who find the winter a rather lean season. The largest catches of croakers are made during the spring (March, April, and May), when the prices drop. About 15 to 20 years ago the croaker was taken in such large quantities in the spring of the year that the dealers were unable to find a market for all of them, and at times the fish were wasted. The senior author has seen the shores in the bight at Cape Lookout literally covered with dead and decaying croakers, usually of rather small size, which the fishermen had sorted from their catches and thrown away because they could not sell them. This has not happened during recent years, probably largely because of better marketing facilities.

The croaker generally is considered inferior in flavor to many other species, and it seldom commands a fancy price. It is wholesome, however, and it meets a demand for a cheap and a nutritious fish. Locally its importance increases, as already pointed out, because it may be taken during the winter when other fish are scarce.

Young croakers, ranging from recently hatched larvæ only a few millimeters long to fish an inch or so in length, are present in the harbor and its arms throughout the winter, whereas the larger fish generally are scarce or missing in these shallow waters. The croakers that are marketed during the winter, to which reference is made in a foregoing paragraph, are caught chiefly with sink nets (that is, gill nets that are weighted and sunk to the bottom) set usually in about 6 to 7 fathoms of water.

The winter fishery for croakers (and other species) although pursued intermittently for years may be said to be of rather recent origin, as it was not carried on regularly prior to the World War. It is subject to considerable fluctuation. The past winter (1929–30), for example, the fishery was not very remunerative off Beaufort Inlet, and the fishermen transferred their activities chiefly to Ocracoke and Hatteras Inlets, where the fish were more plentiful this season.

It is shown in the foregoing paragraphs that the croaker makes fall and spring migrations, similar to those of the spot, as explained in that section of this paper which contains a discussion of the last-mentioned species. However, the croaker, unlike the spot, is not known to school locally. Its abundance in the spring seems merely to result from extensive migrations from the winter home to the shallow-water feeding grounds for the summer. Another season of abundance occurs in the autumn, which apparently marks the exodus from the summer feeding grounds. It has been stated that large croakers, like large spots, either are entirely absent or very scarce during the winter in the shallower shore waters where fishing operations are carried on. The same situation as in the spot prevails; that is, the very young (the fry) are present in the harbor and its arms throughout the winter. Between cold snaps larger fish, ranging from a few to 6 or 7 inches in length, may be present also. The last-mentioned sizes and somewhat larger ones, apparently, are present nearly always off Beaufort Inlet in water ranging from a few to several fathoms in depth, but are especially numerous during the winter. The very small fry, ranging from about 2 to 10 or 15 millimeters in length, are common along the banks during the winter (the spawning season) and may be taken at least as far offshore as 12 to 15 miles. (How much farther offshore they occur is not known, as collecting was not extended beyond the distance stated.) The somewhat larger young, ranging from 10 to 25 millimeters in length, seem to be much more numerous within the harbor than off Beaufort Inlet and have been taken at various times in almost countless numbers with an otter trawl, the cod end of which was covered with bobbinet.

The winter home of the large or adult croakers remains unknown. However, there is reason to believe that they do not go far away and that they probably are only a comparatively short distance farther offshore than the smaller ones, which inhabit the shore waters to a depth of 6 to 9 fathoms, beyond which fishing operations are not easily extended with the equipment in use. The chief reason for believing that the larger croakers are not far away is the presence of very small fry—only a few to several millimeters in length—throughout the winter. Such small fry, many of them less than 5 millimeters long, are comparatively helpless and could not have swum far. The larger fish taken along the shores during the winter, with few exceptions, obviously are too small to be mature. It seems reasonable to believe, therefore, that the larger, mature fish, producing the eggs from which the young result, are occupying water not a great distance offshore.

The indications are that young croakers, like the young spot, are less sensitive to low temperature than the larger ones, although other factors not understood may be involved. However, in January, 1927, when the water temperature at the laboratory pier dropped as low as 5° C., as described on page 417, many croakers, ranging from 7 to 10 inches in length (also spot, pigfish, and white perch), became numb and drifted ashore within the harbor. No mortality was noticed among the smaller fish at that time. Furthermore, the fry have been taken repeatedly within the harbor in large numbers and in a very active condition during cold snaps when the larger croakers were absent. It seems rather certain, therefore, that the young are less sensitive to low temperature than larger fish.

SPAWNING

The eggs of the croaker, if taken, have not been recognized. It is highly probable, though, that they have not been secured, as winter towings (that is, during the spawning season of this species) have yielded very few eggs not already known. Furthermore, the writers have seen only one croaker—a female 170 millimeters (6.8 inches) long—taken at Beaufort on October 16, 1926, which contained fairly well developed roe, notwithstanding that numerous fish were examined over a period of several years. J. H. Potter, a local fish dealer of long experience, states that he has seen croakers with roe only in August. Walter Dudley, a local fisherman of many years' experience, claims to have seen croakers with roe from time to time during the fall of the year. Since the young were taken first in September and throughout the winter, croakers with roe, of course, would be expected during the late summer, fall, and winter. Due to the very long spawning season, as shown by the presence of very young croakers in the local waters over a long period of time, it seems probable that no large number of fish become heavily roed at any one time. Furthermore, during the greater part of the spawning season large, mature croakers are very scarce or absent in the shallower waters where the commercial catches and our collections were made. It is not surprising, therefore, that croakers with roe are not seen often locally. Fish in spawning condition apparently are seen more frequently in other localities, as shown subsequently.

Very small fry, less than 10 millimeters in length, appear in our collections for every month from September to May. In other words, recently hatched young were taken every month in the year, exclusive of June, July, and August. The presence of very small fry in the local waters seems to show conclusively that spawning occurs during nine months of the year. The larvæ were not plentiful in September, but they were taken in considerable abundance from October to March, again becoming fewer in April and May. From the comparative abundance of the young in our collections, made over a period of four years, it may be concluded that, although some spawning takes place from September to May, the principal spawning period at Beaufort extends from October to March.

Pearson (1929, pp. 196–198) caught larval and postlarval croakers on the coast of Texas, in Aransas and Corpus Christi Passes, from October to February but they occurred in greatest abundance in November. He concludes, therefore, that in Texas the height of the spawning season occurs in the last named month. Pearson, unlike the present investigators, seems to have had no difficulty in finding ripe adult croakers which, he states, were migrating from the bays to the Gulf during September and October.

Welsh and Breder (1923, p. 180) state, "The spawning season is a long one, extending from August to December and possibly later in southern waters." These investigators had taken males with running milt at Atlantic City, N. J., early in July and, although they had not seen ripe females, they judged by the size of the young caught in Chesapeake Bay and in New York Bay in September, which ranged from 22 to 41 millimeters in length, that spawning must occur as early as August. If the size of the young caught in these more northern waters may be accepted as a criterion, then spawning must begin earlier in Chesapeake Bay and northward than it does in the vicinity of Beaufort, for we have no fry over 9 millimeters in length for September. Pearson (loc. cit.) did not get the fry in Texas until October, when this new year class had "a mode around 1 centimeter."

Hildebrand and Schroeder (1928, p. 284), working with fishes from Chesapeake Bay, agree essentially with Welsh and Breder (loc. cit.) relative to the duration of spawning. The first named authors found croakers with well-developed roe "common" during October and early in November which they believed to be the principal spawning period in Chesapeake Bay. These investigators took specimens of the O class in October which were 10 to 105 millimeters long; in November the range in the length of specimens assigned to this year class was 15 to 116; in December, 11 to 120; in January, 10 to 110 (none reported for February); and in March the range was 32 to 64 millimeters, the largest fish of this year class not being represented. The absence of very small fish in the catches after January suggests that spawning may end in December or January in Chesapeake Bay, whereas at Beaufort fry 3 to 15 millimeters long were common as late as April. (Table 9.) It is of interest to note that Pearson (1929, p. 200, Table 28) took a single specimen around 10 millimeters in length in February, none much less than 30 millimeters in March, and only 2 around 20 millimeters in length in April. It would appear, therefore, from published accounts and the present investigation, that spawning probably begins in August in Chesapeake Bay and northward, in September at Beaufort, and in October in Texas; also, that it probably ends in December or January in Chesapeake Bay and northward, in April at Beaufort, and in February in Texas.

A spawning season of about nine months' duration, as found at Beaufort, must be considered an exceptionally long one. It is by far the longest reproductive period known to the writers among oviparous fishes. Such a long spawning season suggests the possibility that we are dealing with more than one species. It is pointed out in a preceding paragraph that the croakers inhabiting the brackish to fresh waters during the summer run larger in size than those from strictly salt water and, furthermore, they have pinkish to reddish pectoral, ventral, and anal fins, whereas these fins are pale to slightly yellowish in the salt water inhabiting croakers. These differences may be due entirely to environment, but the fish are worthy of a much more detailed study than they have received to date. It would not be surprising if a thorough study would reveal structural differences; possibly somewhat different, yet overlapping, spawning periods; and finally that they are separate and distinct species. The fact that few croakers seem to contain spawn at any one time at Beaufort, as shown in a preceding paragraph, however, militates somewhat against the 2-species theory.

The almost total absence of adult croakers from the shallow shore waters during the greater part of the chief spawning period, as already pointed out, shows almost conclusively that the eggs at that time are not deposited in these shallow waters. The distribution of the very small fry, on the other hand, indicates that the eggs can not be cast at a great distance from the harbor. Young fish, only 3.5 millimeters long, have been taken in the harbor during the winter and smaller ones, some of them slightly under 3 millimeters, have been collected on the outer shores of the banks. These small fry, and especially somewhat larger ones, usually are common to abundant throughout the winter and are quite generally distributed in the waters wherein towings were made, extending from the estuaries through the harbor and a distance of about 15 miles out to sea. Fry only 3 or 4 millimeters in length are helpless creatures; they are without developed fins, and no doubt are wafted from place to place by winds and tides. Therefore, under ordinary weather conditions, with only about 3 feet of tide, with fairly deep water near shore, and without definite shoreward currents except during flood tides, it seems reasonable to believe that such small fry must have been hatched at a comparatively short distance from the place of capture.

The smallest fry taken (2.8 millimeters long), although probably only a few days old, already had absorbed all the yolk. We judge, from our knowledge of the size of young hatched from ova of various diameters, that the egg of the croaker is somewhat less than a millimeter in diameter. Such small eggs, according to our observations, invariably have a very short incubation period which quite certainly would not exceed a week, even during the coldest weather which prevails locally. It seems unlikely, therefore, that the eggs, if they be buoyant, would drift far during the short incubation period, and it seems reasonable to expect them to be cast at no great distance from the place where they are hatched.

For the reasons advanced in the two preceding paragraphs, it seems rather certain that while the eggs are not deposited within the harbor nor immediately offshore at sea, they are cast at no great distance (probably 30 miles or less) from the outer shores of the banks, which accordingly would constitute the chief spawning ground of the croaker in the vicinity of Beaufort.

Welsh and Breder (1923, p. 180) say, "Spawning takes place in the larger estuaries, such as Delaware and Chesapeake Bays," and Pearson (1929, p. 196) states that on the coast of Texas croakers spawn "in the open Gulf of Mexico near the mouths of the various passes that lead into the shallow bays and lagoons." It seems probable, therefore, that the croaker generally, at least, deposits its eggs in large open waters.

The number of eggs produced appears to be large, for Hildebrand and Schroeder (1928, p. 284) found approximately 180,000 eggs of uniform size in a specimen 15.5 inches long, taken in Chesapeake Bay.

DESCRIPTIONS OF YOUNG

Specimens 2.8 millimeters long.—The mouth is large and nearly vertical; the body is rather deep, the caudal portion being comparatively quite deep, becoming slender only near the tip where it terminates in a sharp point. The dorsal outline is quite regular and rather evenly convex. The visceral mass is rather small. The hind-gut is very evident and it projects rather prominently, but it does not appear to be wholly free distally. Fin folds are visible only along the ventral edge of the caudal portion of the body and around the extremely slender distal part of the tail, and are wholly without indication of rays. Pigmentation consists of a dark crescent-shaped area above the visceral mass where the dark peritoneum is visible through the body wall; also a row of dark points along the ventral edge of the caudal part of the body, and an indistinct dark spot at the point of articulation of the mandible. (Fig. 51.)

Specimens 3.6 millimeters long.—The most conspicuous change, while the fish grows from a length of 2.8 millimeters to 3.6 millimeters, takes place in the development of the tail. The notochord has become bent upward slightly, and rudiments of fin rays are evident in the fin fold below the curved notochord. These rays, although directed obliquely downward, are destined to become horizontal in position and to form the caudal fin. Fin rays are not yet evident elsewhere. The viscera at this age (size) appears more firmly connected with the body and smaller in size than in younger individuals. The hind-gut, however, remains conspicuous and appears to be connected with the body, both anteriorly and posteriorly, by semitransparent membranes only.

Specimens 4.0 millimeters long.—At this age (size) the notochord is bent upward prominently and the caudal fin is well formed, the rays now being in a horizontal plane. The upward curve in the notochord gives the tail the appearance of being heterocercal. A thickening of tissues has occurred in the area to be occupied by the base of the anal. A similar development is evident for the base of the soft dorsal. The hind-gut remains prominent and the vent is becoming situated near the anal, the distance between it and the origin of the anal being shorter than the diameter of the eye. The pigmentation remains the same as in the very young, except for a few black chromatophores that now have appeared around the hind-gut. (Fig. 52.)

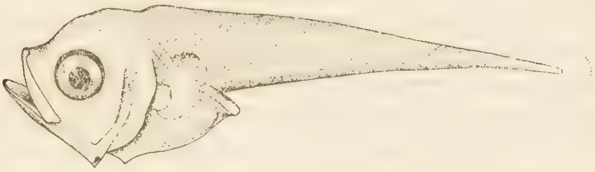

FIGURE 51.—*Micropogon undulatus.* From a specimen 2.5 millimeters long

Specimens 6.0 millimeters long.—At this size the soft dorsal and the anal fins are fairly well developed and it is possible to make a reasonably accurate count of the anal spines and rays. Some of the rays in the dorsal fin (especially the posterior ones), however, are not fully enough formed to permit of enumeration. The caudal fin is well developed. The heterocercal character of the tail is still evident, but in addition to the upward-curved notochord (now ending at the base of the upper rays of the fin), the backbone also has become visible at the base of the caudal. Pectoral fins for the first time are evident, but the ventrals appear to be undeveloped. The mouth is still quite oblique but much less so than in the very young. (Fig. 53 is based on a specimen 7 millimeters long and, therefore, in general a little further developed than the specimen just described.)

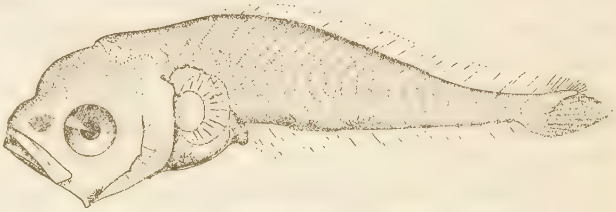

FIGURE 52.—*Micropogon undulatus.* From a specimen 4 millimeters long

Specimens 10.0 millimeters long.—The soft dorsal is now fully formed; the spinous dorsal is only partly developed, as all the spines are not yet visible. The caudal fin is quite long and its posterior margin is strongly convex. The heterocercal character of the tail remains only faintly visible. The pectoral fins are fairly well developed and the ventrals are just becoming visible appearing as slight tufts of membrane. (Fig. 54 is based on a specimen 12.5 millimeters long and, therefore, represents a stage in the development about midway between the 10-millimeter specimen just described and the 15-millimeter one described in the next paragraph.)

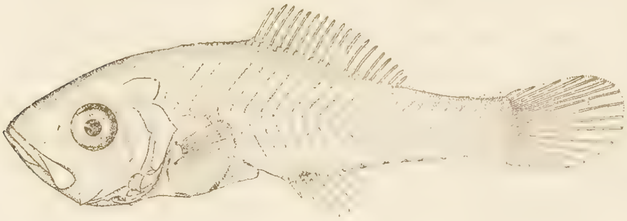

FIGURE 53.—*Micropogon undulatus.* From a specimen 7 millimeters long

Specimens 15.0 millimeters long.—No outstanding changes in development have taken place since a length of 10.0 millimeters was reached. The spinous dorsal is now well enough formed to permit of a reasonably accurate enumeration of the spines, although the posterior ones (which appear last) are still very short and feeble. The heterocercal character of the tail, described for smaller specimens has disappeared completely. The caudal fin has become longer and more pointed; the anal fin is well developed and the second spine has become much enlarged; and the pectorals and ventral have become much larger and now have definite rays. Prominent serrations are present on the opercle and preopercle. General pigmentation has not yet taken place. The blackish spot at the articulation of the mandible, described for specimens 2.8 millimeters long is still present; a row of 4 black chromatophores is present on the median line between the isthmus and the vent; a prominent black chromatophore lies at the base of the first soft ray of the anal; a row of 5 is situated on the median line between the end of the anal and the base of the caudal; and about 3 black chromatophores are situated on the base of the caudal fin. The rest of the body remains unpigmented.

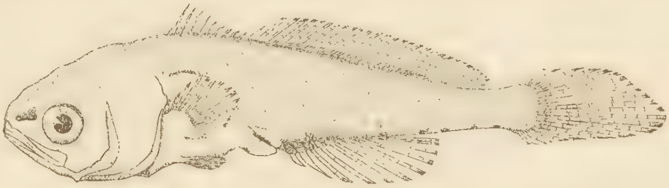

FIGURE 54.—*Micropogon undulatus.* From a specimen 12.5 millimeters long

Specimens 21.0 millimeters long.—The body at this age (size) as in younger ones, is somewhat more slender than in adults, the depth being contained in the length about 3.4 times, whereas in adults it is contained about 2.9 times in the length. The mouth is still oblique (although much less so than in very small specimens) and terminal. Pigmentation has progressed somewhat but it has not become general. In addition to the markings described for specimens 15.0 millimeters long, specimens 21.0 millimeters long have a row of about 6 dark chromatophores, extending from the nape to the end of the dorsal base and another row of about 4 dark spots along the middle of the side, between the point of the pectoral and the base of the caudal. (Fig. 55.)

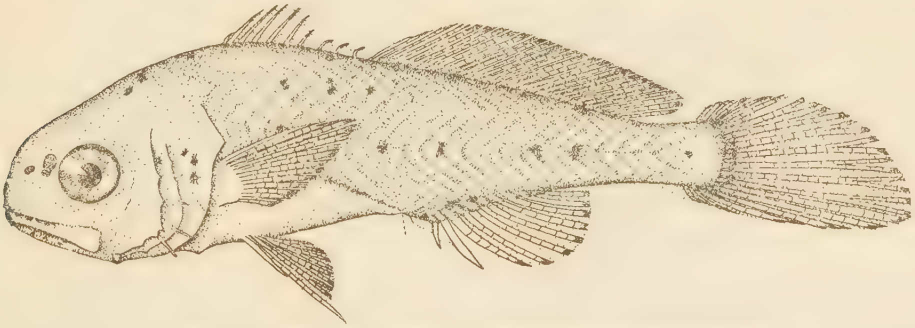

FIGURE 55.—*Micropogon undulatus.* From a specimen 20 millimeters long

Specimens 30.0 millimeters long.—Scales at this size (age) are becoming visible for the first time, and they are present and partly formed nearly everywhere on the head and body. The mouth is nearly but not quite horizontal and slightly inferior and the spines (serrations) on the preopercle and subopercle are large and sharp. The middle rays of the caudal fin are much produced, being nearly equal to the length of the head. General pigmentation has not yet taken place but dark chromatophores have multiplied greatly in number and are scattered over most of the body, the largest ones being visible with the unaided eye. Barbels on the mandible appear to develop very unevenly, being evident in some specimens of this size, whereas they often can not be found in specimens considerably larger. (Fig. 56.)

Specimens 50.0 millimeters long.—Many of the characters of the adult have been acquired at this size, yet the young fish in general appearance is rather strikingly different from the adult. The caudal fin is still long and pointed, the snout does not yet project beyond the premaxillaries; and the mouth remains a little oblique. A row of barbels on the chin generally is evident and the scales are quite fully formed. They have free edges and are beginning to show their ctenoid character. Pigmentation has progressed fairly rapidly since the last-described age (length 30.0 millimeters), but it has scarcely become general. When viewed with the unaided eye, there are now present principally three rows of dark spots; one along the edge of the back, forming with their fellows of the opposite side more or less saddlelike blotches; another row occupies the middle of the side; and a third row lies between the two rows already described.

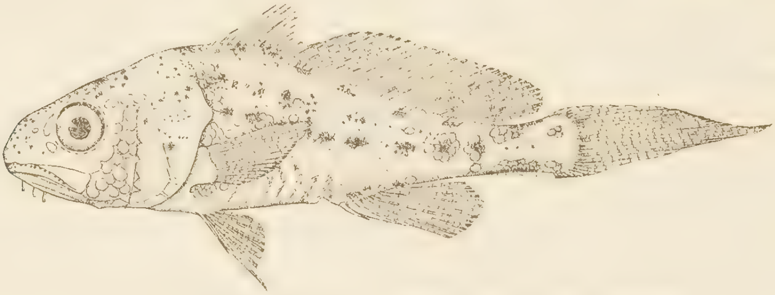
FIGURE 56.—*Micropogon undulatus.* From a specimen 32 millimeters long

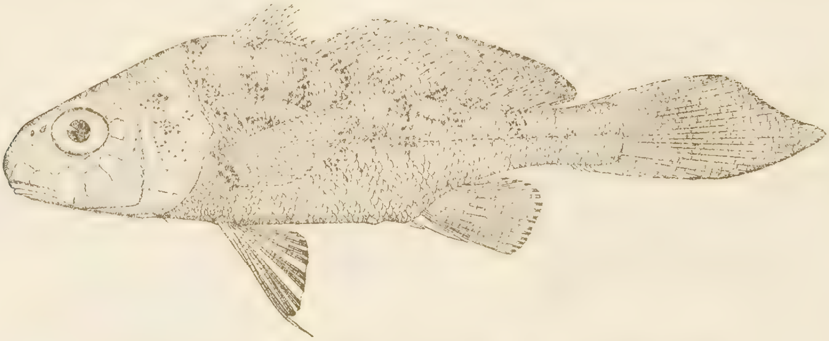
FIGURE 57.—*Micropogon undulatus.* From a specimen 65 millimeters long

Specimens 65 millimeters long.—The mouth is horizontal, the snout projects slightly beyond the premaxillaries; and the lower jaw is definitely included. The back is less prominently elevated than in the adult and the ventral outline is scarcely as straight. The caudal fin remains pointed, but is becoming proportionately shorter. Pigmentation has become general, the sides are largely silvery, shading into a silvery-gray and green toward the back and pale silvery underneath. A more or less definite dark blotch is evident on the opercle; the other dark markings described for 50-millimeter specimens have increased in size and are about to become connected and to form wavy bars, characteristic of the adult. (Fig. 57.)

Specimens 110 millimeters long.—It is not until the fish attains a length of 100 millimeters or more that it acquires the characteristic shape and color of the adult. At a length of 110 millimeters the back is prominently elevated; the ventral outline, from the chin to the vent, is straight; the snout projects prominently beyond the inferior horizontal mouth; and the margin of the caudal fin is approaching the slightly double-concave shape of the adult with the upper and middle rays longest. Although serrations on the opercle and preopercle are less prominent than for a somewhat smaller size they are larger than in the adult. The characteristic color of the adult, including oblique wavy bars (dark in preserved specimens, brassy to brownish in life) on the sides, a dark blotch on the opercle and another at the base of the dorsal, is well developed. The fish would be recognized readily at this size by anyone who knows the adult. (Fig. 58.)

DISTINGUISHING CHARACTERS AMONG YOUNG SCIÆNIDS

The extremely close resemblance between young croakers and spots makes the following comparison appear of value in identifying small specimens. Unfortunately many of the differences are only of degree and are difficult to apply unless specimens of like size of both species are available for comparison.

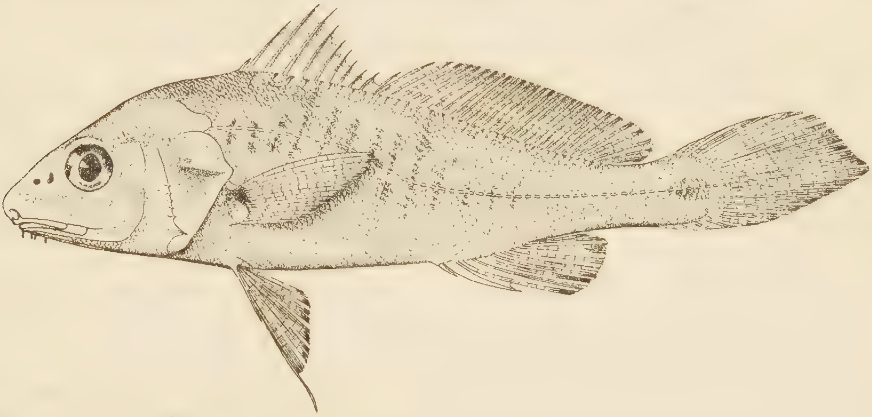

FIGURE 58.—*Micropogon undulatus.* From a specimen 110 millimeters long

SPOT	CROAKER
LENGTH, 2.5 MILLIMETERS	
Caudal portion very slender, an abrupt break occurring in the ventral contour between the abdominal and caudal parts of body.	Caudal portion of body notably deeper, the break in the ventral contour much less pronounced.
LENGTH, 3.5 MILLIMETERS	
General development progressing slowly; no indications of rays in the caudal and dorsal fins.	General development a little further advanced; indications of rays in the caudal and dorsal fins present.
Notochord not bent upward posteriorly.	Notochord bent upward posteriorly.
Caudal portion of body very slender.	Caudal portion of body deeper, tapering more strongly posteriorly.
Eye comparatively large.	Eye smaller. This difference evident only when specimens of even size are compared.

SPOT—continued	CROAKER—continued
LENGTH, 6 MILLIMETERS	
Anal rays not definitely developed, the articulations between the rays and the interhæmal spines, however, are evident and, although a definite count generally can not be made, it is clearly evident that the anal base is a long one.	Anal fin developed about as in the spot. Although a definite count usually can not be made, it is evident that the fin base is shorter than in the spot.
Caudal fin imperfectly developed and short.	Caudal fin somewhat better developed, longer, and more pointed.
Body at origin of anal quite slender in proportion to the anterior part of body.	Body at origin of anal proportionately much deeper.
Vent usually more than an eye's diameter in advance of anal.	Vent always less than an eye's diameter in advance of anal.
Eye large.	Eye somewhat smaller.
LENGTH, 10 MILLIMETERS	
Body at origin of anal comparatively slender, tapering gradually to caudal peduncle.	Body at origin of anal deeper, tapering more abruptly to caudal peduncle.
Anal fin with II, 12 or 13 rays, the spines rather weak.	Anal fin with II, 7 or 8 rays, the spines, especially the second one, much larger and stronger.
Caudal fin moderately long and round.	Caudal fin longer and strongly pointed.
Dorsal spines largely undeveloped; that is, they are just beginning to appear and have no free points.	Dorsal spines better developed, with free points.
Eye comparatively large, nearly as long as snout.	Eye smaller, shorter than snout.
Vertebræ 10 or 11+14 or 15.	Vertebræ 8 to 10+15 or 16.

The similarity of the young spot and croaker (*Leiostomus xanthurus* and *Micropogon undulatus*) on the one hand and the red and black drums (*Sciænops ocellatus* and *Pogonias cromis*) on the other is pronounced and separation is difficult until a sufficient size (about 6 to 10 millimeters) is attained to admit the enumeration of the fin rays. Specimens less than 5 millimeters long of the red and black drums are not available for comparison. However, at a length of 5 millimeters the drums generally may be separated from both the spot and croaker by the presence of dark markings along the back which are entirely wanting in the spot and croaker of this size and for some time afterwards. According to Pearson (1929, pp. 139 and 158) the dark chromatophores appear on the upper parts of the body of both drums at an early age and, therefore, may be used, also, in identifying young less than 5 millimeters long of the species under consideration. Furthermore, at a length of about 3 millimeters a rather definite row of dark chromatophores, about 3 to 7 in number, usually appears along the ventral edge of the tail (caudal peduncle after the anal fin is developed) in the spot and croaker. These color markings seem to be missing in the drums. In specimens about 7 millimeters long and until pigmentation becomes general the drums are much more profusely spotted than the other two species.

In addition to the differences in color markings already noted, the spot and croaker have a somewhat deeper body at a length of 5 millimeters and a slightly larger eye than either species of drum. The differences are evident only when specmens of like size are compared and are not readily used in making identifications.

It is understood, of course, that the most reliable characters for the identification of all of these species are the ray counts of the dorsal and anal fins as soon as these members are sufficiently developed to make an enumeration possible. On this basis the spot is readily separated from the other three species by the long anal fin which consists of 2 spines and 12 or 13 soft rays, whereas the croaker and red drum each have only 8 and the black drum only 6 or 7 soft rays in addition to 2 spines. The croaker, red drum, and black drum all differ in the number of dorsal rays, having respectively in the order named I, 28 or 29; I, 23 to 25; and I, 20 to 22 rays.

The only other member of the family Sciænidæ from the vicinity of Beaufort of which the larval development has been studied is the white perch (*Bairdiella chrysura*). The larvæ of this species are readily recognized at a very small size (2.5 to 3 millimeters) by the prominent black coloration over the abdominal mass which quickly develops into a broad, indefinite crossbar.

DISTRIBUTION OF YOUNG

Recently hatched croakers are quite generally distributed throughout the local waters during the winter, or spawning season. They have appeared in towings made as far as about 15 miles offshore (beyond which collecting was not extended) as well as within Beaufort Harbor and adjacent estuaries. The very small fry, only a few to several millimeters long, appear to be more numerous at offshore collecting stations than within the harbor, but for somewhat larger fish (10 millimeters and over) the reverse seems to be true.

The fry, like the adults, as shown by townet collections, dwell principally on the bottom. In towings made with two 1-meter nets hauled simultaneously at the surface and on the bottom, the fry occurred in 23 surface and in 119 bottom collections.

GROWTH

In the present studies an effort was made to obtain information relative to the development and rate of growth of the croaker during the first year. However, older fish often were obtained in the collections, and such fish were measured and the data are included in frequencies in Table 9. Table 10 and Figure 59 include only the measurements of the fish assigned to the O class. Due to the very long spawning period, it is not surprising that the year classes intergrade. Our collections for some of the months are not nearly as complete as desirable, and therefore the measurements are sufficient to show only in a general way the rate of growth of the young until some of them, at least, have attained an age of 12 to 14 months.

It is quite evident that the larger representatives of the O class are missing for several months. For other months intermediate sizes are not included. This seems to be due largely to the methods of collecting, for it was only during the later months of the work that proper methods were developed for collecting fishes too large to be captured with 1-meter townets, yet too small to be caught with the ordinary collecting seines and trawls.

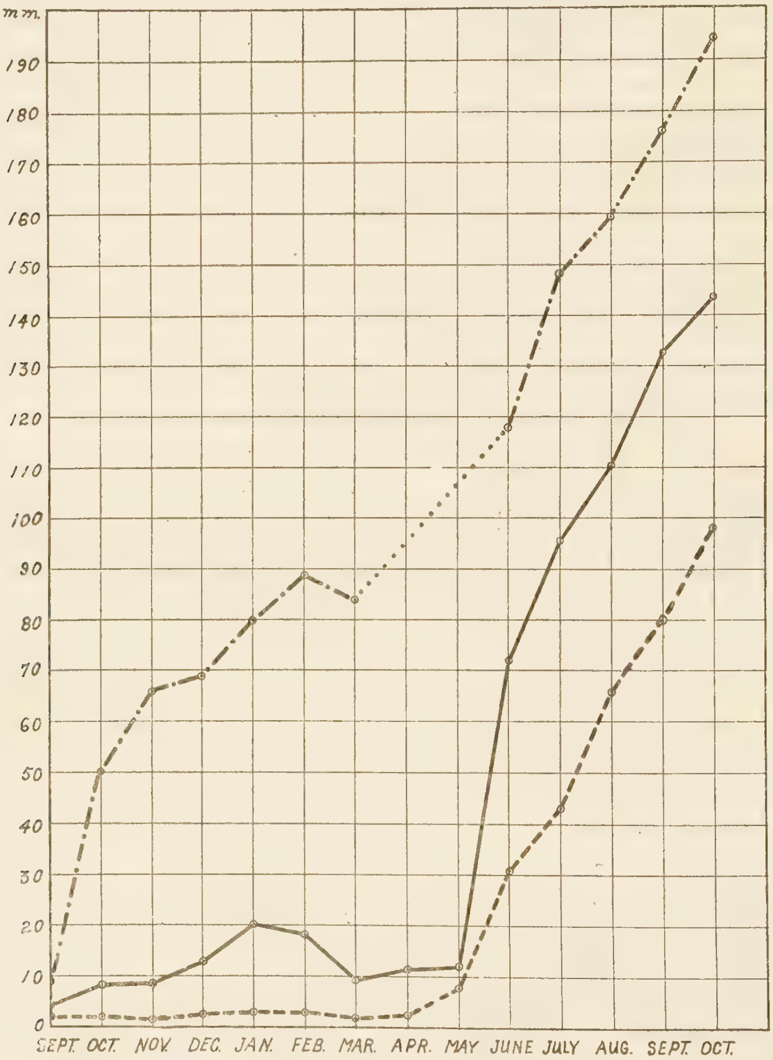

FIGURE 59.—Growth curve of young croakers based on Table 10. Solid line, average of all fish; broken line, smallest fish; dot-and-dash line, largest fish

TABLE 9.—*Length frequencies of 14,184 croakers*

[Measurements to nearest millimeter, grouped in 5-millimeter groups]

Total length	September	October	November	December [1]	January [1]	February [1]	March [1]	April	May	June	July	August
0–4	23	95	36	32	3	2	10	8				
5–9	11	397	404	122	39	38	24	28	2			
10–14		23	278	208	343	427	244	57	22			
15–19		10		10	46	432	59	1	3			
20–24		42			4		4		1			
25–29		13			17	2						
30–34		4		1	10					1		
35–39		4		1	9					4		
40–44			1	9	23	3	1			10	1	
45 49				7	32	9	5			16		
50–54		1		5	20	14	22			13	1	
55–59				4	2	13	36			10	2	
60–64				2	6	9	21			24	4	
65–69			1	6	8	6	7			25	3	1
70–74					2	6	3			30	20	8
75–79					5	9	6			30	50	10
80–84	1				1	9	9			20	89	23
85–89			1	2	2	3				13	139	33
90–94	3			2	2	1	1			12	156	77
95–99		1		5	4	3	4			6	134	95
100–104	7	2		3	22	4	7	1		9	120	190
105–109	7	4		7	15	12	9			3	108	161
110–114	11	12	6	3	16	21	13	1		3	60	176
115–119	23	26	10	8	14	20	8	3		6	28	140
120–124	40	38	13	8	21	27	28	5		1	17	89
125–129	35	52	25	11	22	31	23	1			12	52
130–134	64	74	39	12	39	51	46	9		2	6	60
135–139	75	77	48	9	67	68	74	10		2	5	41
140–144	56	80	46	12	71	104	112	23		3	4	19
145–149	26	62	72	23	57	96	149	34		5	2	19
150–154	9	52	56	20	76	126	221	66		5	6	12
155–159	7	31	63	32	52	144	253	42		9	3	4
160–164	7	28	50	46	52	146	296	49		16	2	5
165–169		25	35	31	44	148	297	45		21	1	7
170–174	2	17	38	22	53	124	246	56		19	3	8
175–179	1	20	30	16	42	81	209	31		15	4	7
180–184		17	32	13	54	76	155	33		24	3	14
185–189		10	29	7	43	44	115	13		11	4	19
190–194	1	2	18	2	36	35	94	11		13	4	10
195–199	4	7	19	4	19	29	68	5		16	3	18
200–204	3	7	25	2	15	23	45	6	2	7	4	14
205–209		5	20	1	9	17	43			5	1	6
210–214	3	7	15	1	2	15	27	4	2		1	13
215–219		4	14		1	16	10	2		2		7
220–224	2	9	10			9	9	1		4	1	2
225–229	1	2	4			4	6		1	2		7
230–234	2	8	6		1	2	3	3		3		1
235–239	2	6	4				1	1	1	3	1	2
240–244	2	7	2					1		3		
245–249	1	2	1			1		1				
250–254	2		5			2	1	1				1
255–259			3	1								1
260–264	3	1	3			1				1		
265–269		1	2		1		1					
270–274						4				1		
275–279	1		1									
280–284			1							1		
285–289												1
290–294		1				1	1					

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[1] The apparent break in the frequency of the O class for the months of December, January, February, and March probably is due to the mode of collecting, for it was only during the last season of the 4-year investigation that a successful method was found for collecting fish too large to be caught in meter townets, yet too small to be taken with ordinary collecting seines and trawls.

TABLE 10.—*Monthly summaries of length measurements of 7,286 croakers during the first year, or so, of life*

Month	Fish measured	Smallest	Largest	Average	Month	Fish measured	Smallest	Largest	Average
		Millimeter	*Millimeter*	*Millimeter*			*Millimeter*	*Millimeter*	*Millimeter*
September	34	2.0	9.0	4.2	April [1]	94	2.5	15.0	11.7
October	589	2.0	50.0	8.2	May [1]	28	8.0	25.0	12.1
November	720	1.5	66.0	8.8	June	236	31.0	118.0	72.1
December	406	2.5	69.0	13.0	July	961	43.0	148.0	95.8
January	570	3.0	80.0	20.2	August	1,210	66.0	159.0	110.6
February	983	3.0	89.0	18.2	September	374	80.0	176.0	132.7
March	451	2.0	84.0	9.4	October	630	98.0	194.0	143.4

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[1] An insufficient number of specimens was secured to show the rate of growth, and the larger representatives of this year class obviously are missing.

The data show that the young fish gain considerable growth during the winter, for some of the larger representatives of the O class, according to our measurements, attain a length of 75 to 80 millimeters (3 to 3.2 inches) in January when, at most, only 4 months old, and the average length for 570 specimens measured is 20.2 millimeters (¾ inch). In June, when the oldest ones are about 9 months old, some of them have attained a length of 100 to 118 millimeters (4 to 4.6 inches) and the average length for 236 specimens measured is 72.1 millimeters (3 inches). In October, when the earliest young of this year's class are about a year old, the largest, according to our data, have attained a length of 175 to 194 millimeters (7 to 7.8 inches) and the average length for 630 specimens is 143.4 millimeters (5.7 inches).

The rate of growth, as shown by our data, does not differ greatly from that found in Texas by Pearson (1929, p. 198 to 200), who indicates, for the month of May, a mode for the O class at 80 and for the I class at 180 millimeters. Unfortunately, our data for May are too incomplete for comparison, but for June they show a mode at 70 for the O class and 175 millimeters for the I class. Therefore, the data indicate a somewhat slower rate of growth in North Carolina than in Texas.

The present writers did not make a special effort, as stated elsewhere, to determine the rate of growth of the croaker after an age of about 1 year is attained and have nothing to offer, other than the measurements of the older fish contained in Table 9. Pearson (loc. cit.) working with Texas fish found a modal length in May of 240 millimeters (9.4 inches) for fish in their third year and 280 millimeters (11 inches) for those in the fourth year. Welsh and Breder (1923, p. 183) working with Atlantic coast fish, taken from New Jersey to Florida, indicate a modal length of 220 millimeters (8¾ inches) for fish in their third winter and 265 millimeters (10½ inches) for those in the fourth winter.

It is noteworthy that the croaker and the spot, both winter spawners, whose young appear to be similar in habits and occupy very largely identical feeding grounds, grow about equally fast during the first several months of life. It has been shown, both for the spot and the croaker in Tables 8 and 10, that the maximum size attained by these species at 1 year of age, for example, is about 175 to 190 millimeters (7 to 7.6 inches). Our records of lengths and weights, furthermore, show that examples of equal size of the two species at this age are nearly equal in weight; that is, fish 7.5 inches long weigh close to 3 ounces each. These fish in part, at least, enter into the commercial catches made during the winter, with sink nets set off Beaufort Bar, as reported elsewhere in this paper.

AGE AT SEXUAL MATURITY

The present writers have little to offer on this subject, other than that the largest representatives of the croakers a year old generally have the appearance upon dissection of being sexually quite immature. Yet, the single specimen seen with roe (see p. 433) was only 170 millimeters (6.8 inches) long and, therefore, with respect to size falls into the 1-year class, as shown by Table 10 and Figure 59. Welsh and Breder (1923, p. 183) say, "Maturity is reached at the age of 3 or 4 years." Pearson (1929, p. 201), on the other hand, found "matured" croakers in Texas only 140 millimeters (5½ inches) long, which he judged to be in their second year. He concludes, "It appears, therefore, that sexual maturity must be reached and spawning take place for the first time at the end of the second year of life."

The age attained by the croaker, or its duration of life, remains undetermined

FOOD AND FEEDING HABITS

The croaker, with its inferior mouth and chin barbels, is at once marked as a bottom feeder. The habit of dwelling on the bottom, which no doubt is correlated with bottom feeding, appears to apply equally as well to the young (fry) as to the adults, as shown by the much more frequent catches made at the bottom than at the surface (see p. 441), even though the fry do not have an inferior mouth nor barbels.

Not many stomach examinations were made during the present investigation. However, the literature contains rather full accounts of the foods utilized by croakers of all sizes, except small ones, less than 17 millimeters in length. Welsh and Breder (1923, pp. 183–184) found mollusks, ostracods, copepods, polychæte worms, and fish—named in the order of their apparent importance—in the alimentary tract of 45 specimens, taken in Chesapeake Bay in December, ranging in length from 17 to 42 millimeters. Examples 42 to 62 millimeters long, collected in Winyah Bay, S. C., in July, had utilized a few mollusks and fish and had fed abundantly on polychæte worms. In addition they had utilized amphipods, small crabs, a few shrimp, and unidentified larval crustaceans. The octracods and copepods, abundantly utilized by the smaller fish, were missing in these larger examples. Twenty-four individuals, 90 to 170 millimeters long, taken in Cape Canaveral Bight, Fla., in December had fed on echinoderms, shrimp, and polychæte worms, and 8 examples, 120 to 160 millimeters long, taken in Cape Lookout Bight in December, had fed on polychæte worms and mollusks.

Hilldebrand and Schroeder (1928, p. 284) report for 392 examples (mostly adults), taken in Chesapeake Bay at various times over a period of about two years, the following foods named in the order of their apparent importance: Crustaceans, annelids, mollusks, ascidians, ophiurians, and fish. The first three foods named appeared to be important, whereas the others occurred as mere traces. Only 3 of the 392 croakers examined had fed on fish. It is pointed out, furthermore, that the croaker utilizes as food principally forms that have no direct commercial value.

Pearson (1929, p. 203) reports the following: "Of 60 Texas croakers 21 to 35 centimeters (8.2 to 13.7 inches) long, 55 per cent had eaten shrimp; 13 per cent, annelids; 12 per cent, fish; 5 per cent, crabs; 5 per cent, mollusks; and 10 per cent had a mixed diet. Of 19 fish 14 to 20 centimeters (5.5 to 7.8 inches) long, 21 per cent had eaten shrimp; 63 per cent, annelids; 5 per cent, fish; and 11 per cent had a mixed diet."

In addition to the foods reported in the literature cited the croaker during the summer not infrequently includes Balanoglossus, a wormlike chordate, strongly scented with the odor of iodoform, in its diet. The odor and taste of Balanoglossus penetrates the flesh of the fish, making it quite unpalatable. Such fish are described, locally as being "ticky."

PAREXOCŒTUS MESOGASTER (Bloch). Short-winged flyingfish

This flyingfish is known from all tropical seas. It was first recorded from Beaufort by Radcliffe (1914, p. 414), presumably from specimens taken off Beaufort Inlet by the *Fish Hawk*. In fact, all the many specimens from the vicinity of Beaufort at hand were collected by that vessel when operating from the Beaufort stations during the summer months from 1913 to 1915, and none have been taken during recent collecting expeditions.

This flyingfish, when adult, is characterized by the rather short pectorals which reach only to about the middle of the dorsal base and are colorless. The dorsal and anal bases are equal in length, and the snout is short and blunt. The adult characters are acquired by the young fish at a comparatively small size. The maximum size attained is only about 175 millimeters (7 inches). Its life history seems to be little known.

SPAWNING AND DEVELOPMENT OF YOUNG

The eggs of this species have not been taken or, at least, not recognized. Very small fry, ranging from 3 millimeters upward, were common 20 miles and more off Beaufort Inlet in August and September, 1914. Fry only 3 millimeters or so in length, obviously, are very young and it may be concluded from their presence on the coast of North Carolina that spawning takes place there during the summer.

Specimens 3 millimeters long.—The body is rather more compressed at this size than in the adult, although it is already elongate and shapely. The mouth is vertical and the eye is very large. The vent is situated far behind the middle of the body and all the fins already are evident, although only the caudal contains definite rays. Some specimens at this size already are profusely dotted with black. (This size was not drawn, because no perfect specimens are at hand, and, furthermore, the difference between a 3 and a 5 millimeter fish, which was drawn, is not pronounced.)

Specimens 5 millimeters long.—The body has become a little more robust since a length of 3 millimeters was attained and the caudal fin, which was nearly square previously, now has the lower rays somewhat produced. Rays have definitely developed in the pectoral fins, but none is clearly outlined in the ventrals—dorsal and anal. The development of rays in the pectoral fins prior to their appearance in the dorsal and anal is unusual, as the reverse apparently is true in most fishes. Early development of the pectorals probably takes place because they are destined to become very large fins. Pigmentation varies considerably among preserved specimens. The majority of them appear to be rather profusely dotted with black, although others are quite plain brownish. (Fig. 60.)

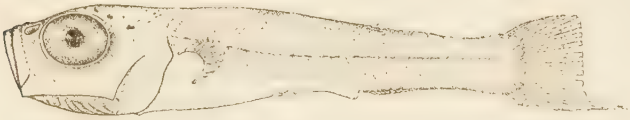

FIGURE 60.—*Parexocoetus mesogaster.* From a specimen 5 millimeters long

The vertical mouth, the very large elongate eye, the almost straight margin of the tail with a few of the lower rays produced, and the presence of dark dots at least on the head are the most outstanding characters of the larval *Parexocoetus mesogaster.*

Specimens 10 millimeters long.—The body is elongate, somewhat compressed, and proportioned much as in the adult. The head is comparatively small and slightly depressed above. The mouth is very strongly oblique but not quite vertical, as in the smaller fry. The fins are all well developed; the pectoral fins are about two-thirds the length of the head; the ventral fins are large, reaching nearly or quite to the origin of the anal; the caudal fin is short above, the rays increasing gradually in length to about the second or third from the lowermost one, the longest rays being nearly twice as long as the shortest. The margin of the fin, therefore, is almost straight and rather strongly oblique. Pigmentation consists of a general brownish cast, the head being paler than the rest of the fish, and the entire body is profusely dotted with black chromatophores, which are crowded along the median line of the side, forming an almost continuous dark line. A few chromatophores also are present on the base of the caudal and extend slightly on the base of the longest rays, the fins being otherwise plain translucent. Some of the specimens at hand are much darker than others, which, however, may be due largely to the method of preservation. The darker-colored specimens appear to be less profusely spotted than the lighter ones. (Fig. 61.)

Specimens 20 millimeters long.—Scales first become evident at a length of about 18 millimeters, although not shown in the accompanying drawing (fig. 62), and at a length of 20 millimeters the body is fully scaled. The pectoral fins are equal to or a little longer than the head, the ventral fins reach the vent, the dorsal fin is high and the rays are slender, reaching slightly beyond the base of the caudal when deflexed. The middle rays of the caudal fin are now a little shorter than the upper ones, making the margin of the fin slightly concave. The upper lobe is short and rounded and the lower lobe is much longer but also rounded. The characteristic shape of the fin in the adult, therefore, is closely approached at this early age. Two short barbels, or dermal flaps, usually, although not always (unless they have been lost in some of the preserved specimens), are present at the symphysis of the lower jaw. Pigmentation remains about as in 10-millimeter specimens, except that dark spots are developed on the ventral and dorsal fins, the dorsal fin being mostly black in some specimens. In some individuals the posterior rays of the anal fin also are dark. (Fig. 62.)

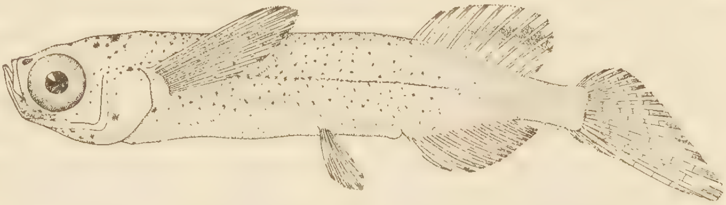

FIGURE 61.—*Parexocoetus mesogaster.* From a specimen 11 millimeters long

Specimens 35 millimeters long.—The body has the shape and form of the adult. A slight keel, in which the lateral line is situated, is present along the ventral edge of the body as in the adult. Two short dermal tentacles usually are evident at the tip of the lower jaw. It is quite probable that normally two tentacles are present. However, they are delicate and no doubt sometimes are lost in preserved specimens. The pectoral fins reach slightly past the base of the ventrals or about to the origin of the dorsal. The ventral and dorsal fins are proportionately as large as in the adult, for the ventrals reach to or a little past the origin of the anal and the longest rays of the dorsal reach a little beyond the base of the caudal. The caudal fin with its long lower lobe and upper short one is slightly forked and shaped virtually as in the adult. Pigmentation remains about the same as in 20-millimeter specimens, except that the dark chromatophores on the body have decreased slightly in size and probably in number and have become profuse on the large pectoral, which is plain translucent in fish 20 millimeters and under in length. (Fig. 63.)

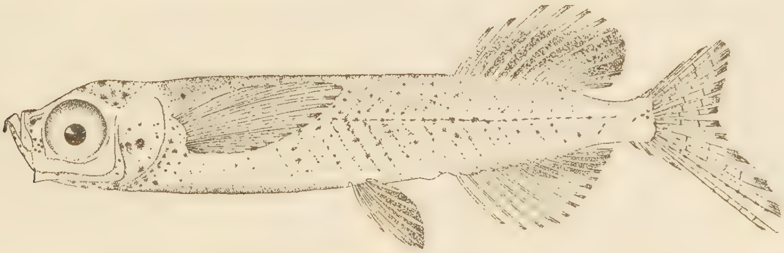

FIGURE 62.—*Parexocoetus mesogaster.* From a specimen 18 millimeters long

Specimens 45 millimeters long.—At this size the fish virtually has all the characters of the adult. While the body acquires essentially the shape and form of the adult at a much smaller size, the adult colors are not acquired until the fish attains a length of about 40 to 50 millimeters. At about this range in size the back becomes dark bluish, the sides silvery, and the underneath parts pale. In the meantime, the dark chromatophores, present on the body in smaller fish, have disappeared. The pectoral fin has increased further in length and now reaches well past the origin of the dorsal, although not opposite the middle of the dorsal as in the adult. Two dermal flaps attached to the tip of the lower jaw, first noticed in specimens 20 millimeters in length, are now about half as long as the eye and, being dark in color in contrast with a light background, they are readily visible.

Specimen 85 millimeters long.—The differences between a fish of this size and those that are about 45 millimeters long is not pronounced. However, at a length of 85 millimeters the pectoral fin has attained the proportionate length of the adult and now reaches opposite the middle of the dorsal base. The dermal flaps at the tip of the lower jaw have increased in length, as shown by the single specimen of this size in the collection, and are nearly as long as the eye. In 20 adult specimens, ranging from 130 to 140 millimeters in length, these flaps are entirely missing. The size attained by the fish at which the maximum stage of development of the dermal flaps is reached can not be stated at this time, because the collection contains only one specimen (85 millimeters long) between sizes ranging from the young 45 millimeters long to the adult 130 to 155 millimeters long. Nor is it known when they again disappear. The use, or significance, of these interesting structures, not present in the very young and again disappearing in the adult, is not understood.

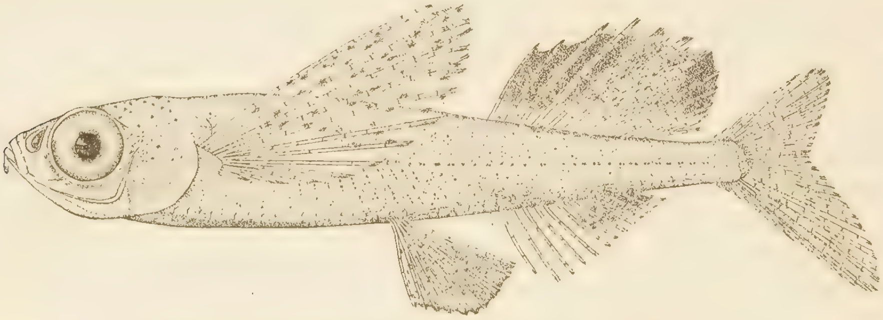

FIGURE 63.—*Parexocoetus mesogaster.* From a specimen 36 millimeters long

DISTRIBUTION OF YOUNG

The numerous specimens of young *Parexocœtus mesogaster* in the present collection all were taken at the surface by the *Fish Hawk*. Since nets suitable for taking the fry were not hauled on the bottom in those areas where the young were taken at the surface, it can not be definitely stated that the young, like the adults, are chiefly pelagic. It is probable, however, that this fish spends its entire life at or near the surface of the ocean.

The young were all taken at stations a considerable distance offshore; that is, in the vicinity of Cape Lookout Lightship, the blackfish (sea bass) grounds, and in the Gulf Stream. Intensive collecting during the past three years (1927 to 1929) with 1-meter townets along the outer shores of the banks and out at sea a distance of about 12 to 15 miles, has yielded no specimens of this flyingfish. Neither were any of the adult specimens at hand taken near the shore. It seems probable, therefore, that this species, on the coast of North Carolina at least, lives at some distance (20 miles and more) from the shore. It is judged from the numerous specimens secured by the *Fish Hawk* that this small flyingfish is common off the coast of North Carolina during the summer.

The rate of growth of this fish, its food and feeding habits, its age at maturity, its range of flight, and many other things about its life history remain unknown.

CYPSELURUS FURCATUS (Mitchill). Four-winged flyingfish

The four-winged flyingfish is known from all warm seas and it occurs on the Atlantic coast of the United States as far north as Cape Cod. However, there is no published record of its occurrence at Beaufort. The 50 specimens in the present collection, with a single exception, were taken off Beaufort by the *Fish Hawk* during July, August, and September, 1914 and 1915, when that vessel was used in carrying on investigations from the Beaufort laboratory. Some of the specimens were taken near Cape Lookout Lightship, others on the sea-bass (blackfish) ground, and a few in the Gulf Stream. A single specimen, about 10 millimeters long, was taken on July 20, 1927, about 6 miles from Cape Lookout. This is the only specimen secured during the systematic weekly collecting trips conducted from 1927 to 1929 and extending from Beaufort Inlet to Cape Lookout and offshore 12 to 15 miles. Neither have the adults been secured near the shores nor within the harbor.

This four-winged flyingfish, when adult, is characterized chiefly by its enlarged ventrals as well as pectorals, the short anal with only about nine rays, and by the pearly-white spot near the base of the ventrals. Many of the adult characters, exclusive of the coloration, as pointed out in the descriptions of the young, are developed at an early age. The maximum size attained is only about 150 millimeters (6 inches). The life history is little known.

SPAWNING

The eggs have not been taken, or at least not recognized. The smallest young in the present collection are about 5 millimeters long. Young of this size, as well as somewhat larger ones, were taken during July, August, and September. It may be concluded, therefore, that spawning off the coast of North Carolina takes place during the summer. Since none of the young were taken very near the shore and the majority of them were secured from 20 to 30 miles offshore, it seems probable that spawning takes place at some distance from the shores.

DESCRIPTIONS OF YOUNG

Specimens 5 millimeters long.—The head is large, robust, and depressed, and the body is notably compressed, the shape at this early age being rather strikingly similar to that of the adult. However, the head is proportionately somewhat broader and more robust, and the body is more strongly compressed. The mouth is very strongly oblique to nearly vertical; the eye is relatively very large and elongate, and the gill covers are exceptionally well developed for such a small fish. The fins are all present, the caudal and pectorals showing a more-advanced stage of development than the other fins. Unfortunately the fins are more or less frayed in our specimens of this size, and their exact shape can not be definitely determined and may not be accurately represented in the accompanying drawing. The ground color of preserved specimens is pale brown, and the entire fish is dotted with large, black chromatophores. Development is far advanced for such a small fish, as some of the adult characters already are evident. In general, the state of development in this flyingfish at a length of 5 millimeters is far ahead of most species studied. (Fig. 64.)

The very oblique mouth, the excessively large eye, and the very prominent dark chromatophores that are quite generally distributed over the body are outstanding characters. The early development of the fins makes an enumeration of the fin rays possible at a remarkably small size.

Specimens 8 millimeters long.—The head is rather less robust than in specimens 5 millimeters long, and the body is a little less strongly compressed, the shape and form being more nearly as in the adult. The mouth is strongly oblique but less so than in smaller fish. The fins have developed rapidly; the pectoral fins are relatively large and broadly rounded, being about twice as long as the eye; the ventral fins reach to, or a little beyond, the origin of the anal; and the margin of the caudal fin is slightly rounded, or more usually nearly straight and oblique, for the lower rays are longer than the upper ones. The color remains essentially as in the 5-millimeter specimen. (Fig. 65.)

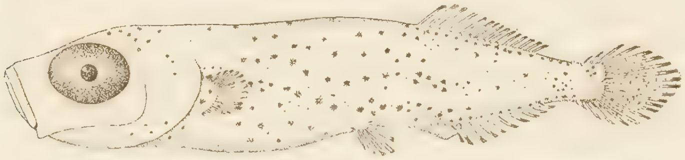

FIGURE 64.—*Cypselurus furcatus*. From a specimen 5 millimeters long

Specimens 12 millimeters long.—The principal advancement in development has taken place in the fins. The pectorals are notably longer than the head and reach nearly or quite to the origin of the dorsal. The ventrals are only slightly smaller than the pectorals and reach well beyond the origin of the anal. The margin of the caudal fin is straight and strongly oblique, the lower rays being much longer than the upper ones. Pigmentation remains about the same as in smaller fish, except that the pectorals and ventrals now are dotted with black chromatophores.

Specimens 18 millimeters long. — The body has become more robust posteriorly and is only slightly compressed. The mouth remains strongly oblique, and it has become proportionately smaller in size. Two dermal flaps about half as long as the eye, not present in the smaller fish, now are evident at the tip of the lower jaw. The margin of the caudal fin is concave, and the lower lobe is much longer and larger than the upper one. Pigmentation has undergone no changes worthy of note since a length of 12 millimeters was attained. (Fig. 66.)

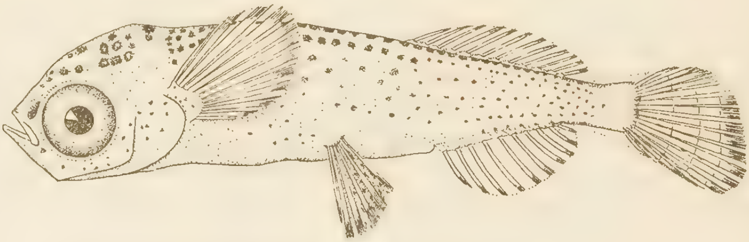

FIGURE 65.—*Cypselurus furcatus*. From a specimen 7.7 millimeters long

Specimens 25 millimeters long.—Scales are not evident on specimens 18 millimeters long. Indications of scale pockets are present, however, and at a length of 25 millimeters scales are well developed although usually lost, as they appear to be loosely attached. The pectoral and anal fins have increased in proportionate length, for the first-named pair now reaches nearly opposite the middle of the base of the dorsal and the other pair reaches to or a little beyond the base of the caudal. These proportions are those attained by these fins in the adult, except that the ventrals in the adult do not quite reach the base of the caudal. Dermal flaps at the tip of the lower jaw are variously developed and occasionally absent. Since these appendages are quite delicate and since the two on the same fish often are of very unequal size, it seems probable that they often are injured and occasionally lost, at least in preserved specimens. The pigmentation on the pectoral and ventral fins has become concentrated in certain places in such a way as to form spots. No other important changes in color are evident. However, some specimens of this size, as well as somewhat smaller ones, have indications of dark crossbars, formed by a concentration of black chromatophores.

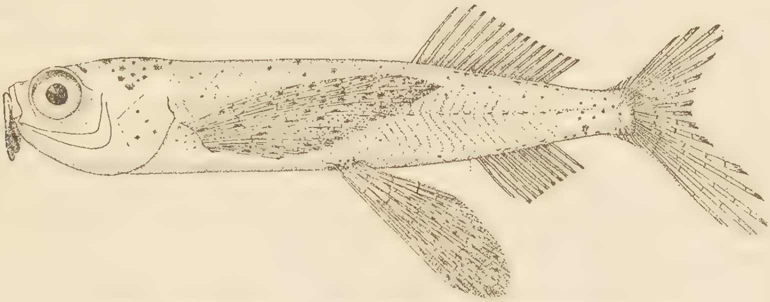

FIGURE 66.—*Cypselurus furcatus.* From a specimen 18 millimeters long

Specimens 35 millimeters long.—The shape and form of the adult has been very closely approximated. The slight keel along the ventral edge of the body in which the lateral line is situated is now visible and causes the body to appear slightly quadrangular in cross section as in the adult. The dermal appendages, inserted at the tip of the lower jaw, are large (about as long as the eye) at this age and have a scalloped outer margin which is black, in contrast with the pale color of the rest of the tentacle. The caudal fin has definitely acquired the shape of that of the adult, being forked and having a small upper lobe and a much larger and longer lower one. All the specimens at hand of this size have dark rings around the body, formed by a concentration of chromatophores. The first dark ring runs across the chest and the base of the pectorals, the third one crosses the base of the ventrals, and the sixth and last very indefinite one lies on the base of the caudal. The pectorals and ventrals are blotched with black and the dorsal bears a few dark chromatophores. The other fins remain plain translucent. The body, of course, is fully scaled at this size. How-

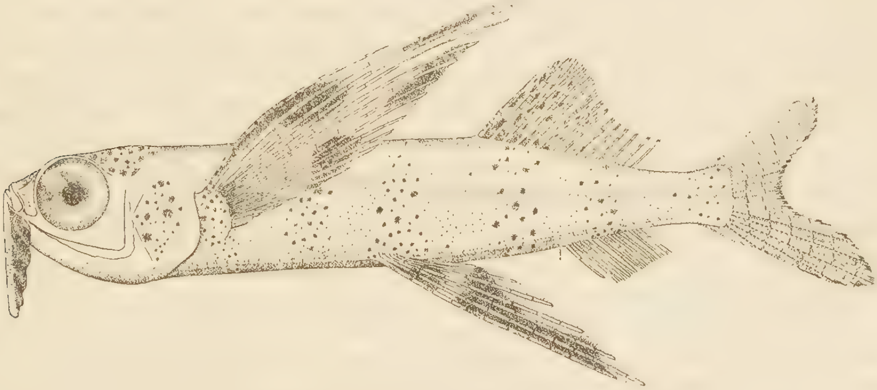

FIGURE 67.—*Cypselurus furcatus.* From a specimen 36 millimeters long

ever, the scales generally are lost and they are not shown on the accompanying drawing. (Fig. 67.)

Specimens 55 millimeters long.—The shape and form of the adult is now fully developed. The dermal tentacles, inserted at the tip of the lower jaw, are comparatively large, reaching slightly beyond the eye in the single specimen of this size at hand. The limited number of specimens of this and larger sizes in the collection indicates that the maximum stage of development is reached at this length. Pigmentation on the body still consists principally of the dark rings described in specimens 35 millimeters long. The pectoral fin now has two dark spots on the outer rays, whereas the inner rays are dark, except at the base and a dark bar crosses the middle of the fin and extends to the tip of the longest rays. Nichols and Breder (1928, p. 448) published a color plate of a fish 65 millimeters in standard length. While we have no specimen of exactly that size, our smaller, as well as larger ones, have much more dark color on the pectoral fins than shown in the color plate. The color of the ventrals is similar, but none of our specimens have dark spots or bars on the caudal fin, as shown in the color plate mentioned.

Specimens 90 millimeters and more in length.—A specimen 90 millimeters in length has rather short dermal appendages at the tip of the lower jaw which reach only a little past the anterior margin of the eye and are only about two-thirds as long as the eye. In color the body is plain, light brown with only a trace of the dark rings, described for smaller fish, remaining on the chest and abdomen. A specimen only slightly larger (95 millimeters) has no trace of dermal tentacles on the lower jaw. The ventral fins do not quite reach the base of the caudal and have attained the proportions of those of the adult. In color it is more uniform and without traces of dark bars or rings. The pectorals and ventrals, however, are very largely black. Two adult fish, respectively 135 and 140 millimeters in length, have no trace of dermal appendages on the lower jaw. Insufficient specimens are at hand to draw conclusions. However, the indications are that in this species as in *Parexocœtus mesogaster* (see p. 448) these dermal tentacles, which are not present in the very young, again are missing in the adult. No specimens with branched barbels, such as is figured by Fowler (1906, p. 288), are included in the present collection. Nor does the coloration of our specimens agree with Fowler's illustration. The dark markings on the pectorals probably vary. However, the ventral fins in all of our specimens of 35 millimeters and upward in length are blotched with black and in a specimen 90 millimeters long the characteristic pearly gray spot of the adult already is developed. Fowler's illustration shows the ventrals unmarked.

Very young *Parexocœtus mesogaster* and *Cypselurus furcatus* may be distinguished from each other by the generally lighter color and the much more profuse spotting with black chromatophores of the body in the latter. At a length of 10 millimeters the ventral fins in *C. furcatus* already are proportionately longer than in *P. mesogaster* and as the fish increase in size this difference becomes more pronounced. Due to the early development of the fins, the species can be separated even at a small size (5 to 10 millimeters) by the enumeration of the dorsal and anal rays, *P. mesogaster* usually having 11 dorsal and 13 anal rays, whereas *C. furcatus* usually has 14 dorsal and 10 anal rays.

DISTRIBUTION OF YOUNG

All of the specimens in the present collection from the vicinity of Beaufort, both adults and young, were caught at the surface. No nets suitable for taking the young on the bottom were used by the *Fish Hawk* which collected all the locally caught specimens, exclusive of one. Since no collecting was done for bottom specimens in the areas where the young were common at the surface, it can not be definitely stated that they are present only at the surface. However, it seems very probable that this species is wholly pelagic throughout life.

It is pointed out in the preceding paragraph that the fish were taken only at quite a distance from the shores. On account of the failure to secure more than a single young fish during the systematic collecting carried on along the shores and out to sea for 12 to 15 miles from 1927 to 1929, and the rather numerous specimens taken farther out at sea by the *Fish Hawk*, it may be concluded that the young are fairly common, at least during the summer, from 20 to 30 miles or more offshore, and that they rarely enter the shore waters in the vicinity of Beaufort.

The rate of growth of this fish, its age at maturity, its range of flight, its food and feeding habits, and many other things concerning its life history remain unknown.

DECAPTERUS PUNCTATUS (Agassiz). Scad; cigarfish; round robin

The scad is known from Cape Cod to Brazil. Although common in a part of its range, as in Florida, it is not numerous enough to be of much commercial importance. The adults are rarely seen at Beaufort and the species was first recorded from that vicinity by Gudger (1913, p. 105), the record presumably being based on a specimen taken at Cape Lookout by the late Dr. Russell J. Coles. The same collector presented 3 fine specimens, all close to 8½ inches in length, to the Beaufort laboratory on August 9, 1913. These fish, also, were caught at Cape Lookout. In addition to the three adult fish, the laboratory collection contains hundreds of young, ranging from about 2 to 50 millimeters in length. Some of these specimens were taken off the coast of North Carolina by the *Albatross* in 1885, and others by the *Fish Hawk* from 1913 to 1915. However, the majority of them, including particularly the very small fry, were caught during the present investigation (1927 to 1929) when systematic collecting was carried on off Beaufort Inlet. Because of the abundance of the young in the local offshore waters (for the species has been taken only once within the harbor), it is believed that the adults must be fairly common, too, although rarely taken.

The adults of the scad are most readily recognized by the elongate, fusiform body, the long dorsal and anal fins (the dorsal with VII or VIII–29 to 30 and the anal with II–I, 25 to 27 rays), each followed by a single detached finlet, and by deep bony scutes in the posterior half, or straight part, of the lateral line. The scad probably is chiefly pelagic and the maximum size attained is about 12 inches.

SPAWNING

The eggs of the scad were not taken, or at least not recognized. Nor were adult fish with roe observed. The presence of the fry in the local waters, however, affords a fairly satisfactory means of determining the time, the duration, and the place of spawning. Very small fry, only about 2 to 4 millimeters in length, which obviously are very young, were taken from May to November. They were most numerous, however, in July, August, and September. It is evident, therefore, that spawning may take place throughout the summer, or from about May to November, but that it is at its height during July, August, and September.

The young were taken anywhere from the outer shores of the banks at Cape Lookout, and offshore to the Gulf Stream. The fry were secured within the harbor only once when they were caught immediately opposite the inlet. It is quite evident, therefore, that spawning takes place at sea and probably anywhere from the shores to, and possibly beyond, the Gulf Stream. The smallest fry taken are only about 2 millimeters long, which suggests that the scad produces very small eggs.

DESCRIPTIONS OF YOUNG

The young fish in the present collection range from about 2 to 50 millimeters in length and within this range the series is fully complete, as all sizes are represented by numerous specimens. However, no specimens ranging from 50 to 175 millimeters in length are at hand. Therefore, young ranging upward of 50 millimeters are not described.

Specimens 2.3 millimeters long.—The head is excessively large and deep and somewhat compressed. The body tapers posteriorly to a sharp point. The dorsal profile of the head is deeply concave, the snout being directed upward. The mouth is large and nearly vertical, and the tip of the lower jaw is above the level of the upper margin of the eye. Comparatively large spines are present on the preopercular bones. (These spines disappear at an early age, or when the fish reaches a length of about 20 millimeters and the preopercular margin, thereafter, is smooth and entire.) Pectoral fin folds are prominent but the ventral fins are not evident at this size, nor in considerably larger specimens. The vent is prominent and is situated somewhat posterior to mid-body length. A few dark markings usually are evident along the dorsal and ventral outlines of the body at the base of the fin fold. Although the fish must be very young at this size, the yolk is all absorbed and the head is fairly well in line with the axis of the body. (Fig. 68.)

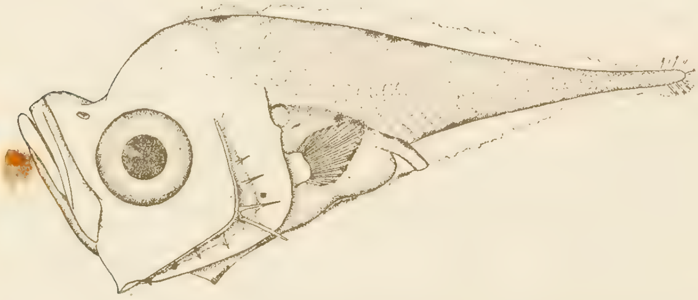

FIGURE 68.—*Decapterus punctatus.* From a specimen 2.3 millimeters long

Young of this size are remarkable on account of their deep heads, turned up snout, and long spines on the preopercular margin.

Specimens 3.5 millimeters long.—At this size the head is not as disproportionately large in comparison with the rest of the fish as in the 2.3 millimeter specimens, for the body has gained greatly in depth, except in the distal part of the tail which remains slender and pointed. The fish is quite strongly compressed and very unlike the adult in this respect. The concavity in the dorsal outline of the head is slightly less pronounced, and the mouth is a little less strongly oblique than in the smaller fish described. The fin fold remains complete and extends from the nape around the tail and forward to the abdomen. The dark chromatophores on the dorsal and ventral outlines of the body, especially on the caudal region, have increased in number and intensity. A few dark chromatophores, also, are present on the median line of the side, posterior to the vent.

The presence of dark chromatophores on the median line of the side are very helpful in recognizing young scad of this size and larger ones, for this row of black chromatophores persists and is prominent until a length of at least 10 to 12 millimeters is attained. At that size the fin rays are developed and identification can be based largely on adult characters.

Specimens 5 millimeters long.—The fish remains deep and compressed. The principal advancement over the 2.3-millimeter fish is the development of fins, for some of the anal, dorsal, and caudal rays are definitely formed. Posteriorly, the notochord is bent upward abruptly, giving the tail a pronounced heterocercal appearance. Preopercular spines are present but proportionately smaller than in younger fish. Chromatophores have increased in number, a few having appeared on the head, and some specimens have 3, others 4, longitudinal rows of black chromatophores on the side extending backward from the vertical of the vent. (Fig. 69.)

Specimens 7 millimeters long.—The fish is much more regular in outline and more shapely than it is in the smaller sizes described. The concavity in the dorsal profile of the head, very pronounced in 2 and 3 millimeter specimens, is very slight at this size. The distal part of the tail has become deeper, much more shapely, and has lost its heterocercal character. However, the body remains deep and compressed. The fins are all developed. The ventrals are very small and were not noticed in smaller specimens. The vertical fins are fairly well developed. However, the spines in the dorsal and anal are scarcely distinguishable from the soft rays and the caudal fin has a round margin. Dark chromatophores have increased in number on the dorsal surface of the head. In other respects pigmentation remains much as in 5-millimeter specimens.

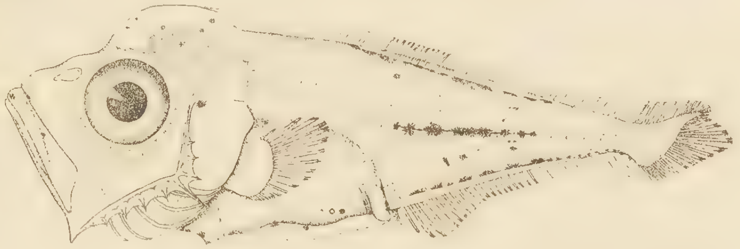

FIGURE 69.—*Decapterus punctatus.* From a specimen 5.2 millimeters long

Specimens 10 millimeters long.—No pronounced advancement in the development, over 7-millimeter fish, is evident. The preopercular spines have become quite small, the mouth is noticeably less oblique than in the very young, and the dorsal outline of the head is regularly convex. The spinous dorsal is differentiated and separated from the soft dorsal by a notch. The spines in the anal fin too are well differentiated, and the caudal fin is slightly forked. A concentration of dark chromatophores has taken place on the head, making a black blotch on the occipital surface. A black line on the middle of the side on the caudal portion of the body is now visible to the unaided eye. This dark line is very characteristic of the young and serves as an early recognition mark. (Fig. 70.)

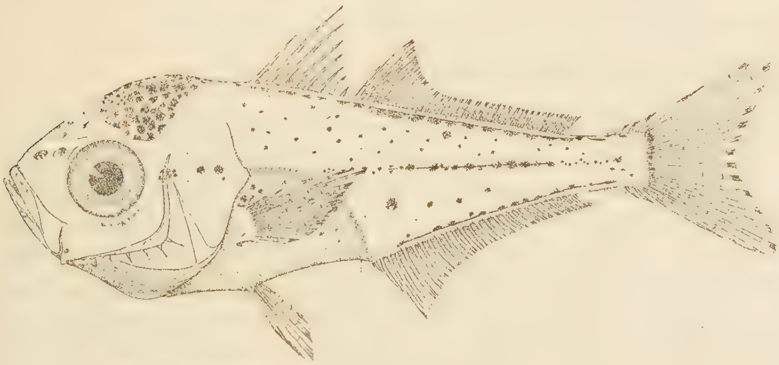

FIGURE 70.—*Decapterus punctatus.* From a specimen 10.5 millimeters long

Specimens 15 millimeters long.—The head is disproportionately large and deep in the smaller fish, being notably deeper than the rest of the body. At a length of about 15 millimeters the greatest depth of the head is equal to the greatest depth of the body and is contained about 3 times in the standard length, whereas in 10-millimeter specimens the greatest depth of the head is contained about 2.5 times in the standard length. Preopercular spines, long and prominent in the very young, are not evident in 15-millimeter fish. The fins are well developed. The ventral fins, which first became evident in specimens 7 millimeters long, are long and prominent in 15-millimeter specimens, reaching to the origin of the anal. The first two spines of the anal are well separated from the rest of the fin, as in the adult, and the caudal fin is rather deeply forked. Preserved specimens of this size, when viewed with the unaided eye, have a brownish cast, especially along the back, a dark blotch over the head, and a dark lateral stripe. Under magnification the individual chromatophores, causing the coloration, are still visible. In life, specimens of this size are quite silvery.

Specimens 20 millimeters long.—The differences between fish of this size and those 15 millimeters long is not pronounced. The body, although still notably compressed, has become more elongated. Scales are not yet present but bony scutes in the posterior part of the lateral line are quite evident. The pores of the lateral line also are plainly visible. (Fig. 71.)

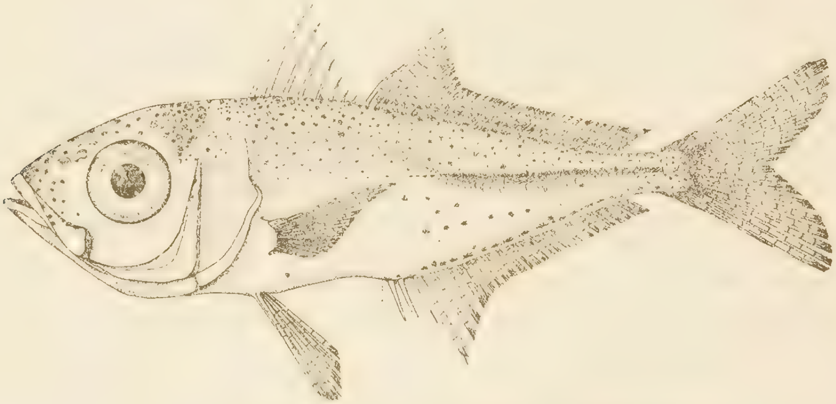

FIGURE 71.—*Decapterus punctatus.* From a specimen 20 millimeters long

Specimens 30 millimeters long.—The body is notably elongate but remains quite strongly compressed, the greatest depth being contained about 3.6 times in the standard length. The snout has become rather pointed, and the mouth oblique and terminal. The tip of the lower jaw is about on the same level as the middle of the eye, and the maxillary reaches to or slightly past the anterior margin of the eye. The mouth therefore has approached very nearly the shape and position occupied in the adult. The bony scutes in the lateral line are developed throughout its length. The scales, being very small, are not definitely visible. The ventral fins are proportionately shorter than in somewhat smaller fish and reach only to the vent. The last two rays of both the dorsal and anal, which are destined to form separate finlets, are united by membrane and entirely undifferentiated from the rest of the fin until a length of about 30 millimeters is attained. At that size a somewhat larger interspace is present between the second and third posterior rays of each fin than between the other rays, but generally a membrane still connects the last pair of rays with the rest of the fin and the finlets are not fully differentiated. The fish now is mostly silvery, the back being slightly brownish in preserved specimens, and the dark lateral stripe, characteristic of smaller fish, has disappeared.

Specimens 45 millimeters long.—The difference between specimens of this size and 30-millimeter ones is not pronounced. The body remains proportionately deeper and much more strongly compressed than in the adult. The greatest depth at this size is contained about 3.8 times in the standard length, whereas in the adult specimens at hand the depth is contained about 4.5 times in the standard length. Scales are quite fully developed but are not shown in the accompanying drawing because of their extremely small size. The ventral fins reach about two-thirds the distance from their insertion to the origin of the anal, whereas in the adult they reach only about one-third of this distance. The single finlet, following the dorsal and anal fins, in each case is now fully differentiated. The color of preserved specimens remains almost wholly silvery. Although fish 45 millimeters or so in length differ in many respects from the adult, such diagnostic characters as the single detached finlet following each the dorsal and the anal; the deep scutes in the posterior part of the lateral line, the rather small oblique mouth, and the silvery color all are developed. It is not very difficult, therefore, to identify 50-millimeter specimens with the adult. (Fig. 72.)

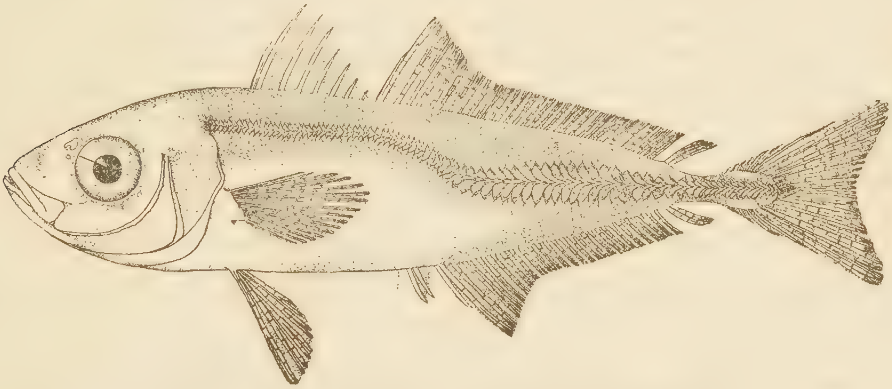

FIGURE 72.—*Decapterus punctatus.* From a specimen 44 millimeters long

DISTRIBUTION OF YOUNG

The young ranging from about 2 to 50 millimeters in length, of which numerous specimens were secured as stated in another section of this account, were nearly all taken at sea at numerous stations extending from the shores of the banks to the Gulf Stream. Only 3 fry were taken in the harbor, and these were collected near the inlet. The numerous specimens collected by the *Albatross* and the *Fish Hawk*, consisting mostly of fish ranging from 15 to 50 millimeters in length, so far as this information is given, were taken at the surface. It is not known that nets suitable for taking these small fish were hauled elsewhere than at the surface. However, during the systematic collecting with townets carried on from the Beaufort laboratory with smaller vessels from 1927 to 1929, when an approximately equal number of drags was made with two 1-meter nets hauled simultaneously—one at the surface and the other on the bottom—fry up to 25 millimeters in length were taken in the surface net 40 times and in the bottom net 49 times. The number of times the fish were taken on the bottom not only is larger but the number of specimens taken there is considerably greater.

It is evident from the collections that the young (up to 25 millimeters in length, at least) occur both at the surface and on the bottom, and it seems probable that they can be taken at any depth (ranging down to 20 fathoms) within the area in which the recent townet collections were made. Evermann and Marsh (1902, p. 129) report the capture with a beam trawl of six young, about 2 inches in length, from near Porto Rico in 220 fathoms of water. It is quite certain from this record and the results of the present investigation that the young scad, at least, is not wholly pelagic.

It is pointed out on a preceding page (p. 453) that the young were secured from May to December. However, only a few were taken in May and June, many in July, August, and September, a few in October, and only a couple of stragglers in November and December. It is evident, therefore, that the fish leave the shore waters upon the approach of cold weather. This exodus from the shallower shore waters was expected, because the scad is principally a tropical species. It is not known, however, whether the fish hatched in the local shore waters during the summer migrate southward or whether they merely move offshore and possibly into the Gulf Stream.

The rate of growth can not be determined from the present collection. The largest specimens are only about 50 millimeters long and were taken in September and October. It is probable that these fish are representative of the largest young of the O class and that a length of 50 millimeters (2 inches), or so, is attained at an age of 4 or 5 months. The food and feeding habits remain largely undetermined. Beebe and Tee-Van (1928, p. 105) list copepods, numerous zoea, and ostracods for a fish 95 millimeters long. The stomach contents of the small fish in the present collection have not been studied.

SERIOLA DUMERILI (Risso). Amberfish; rudderfish

The amberfish, as here understood,[4] inhabits both coasts of the Atlantic, and on the American coast it ranges from Massachusetts to Brazil. It does not occur regularly in the vicinity of Beaufort and has no commercial value there. In 1915, for example, from 2 to 10 individuals, all of nearly uniform size (about 13 inches in length), were taken daily from May 17 to 29, in a pound net operated by the Beaufort fisheries station. These fish were shown to several local fishermen, who did not recognize the fish and could not remember that they had previously seen a fish that looked like it.

Smith (1907, p. 203) says, "A number of years ago, some New Jersey fishermen set pound nets off the beach near Nags Head and for some time caught numbers of fine, large amberfish, and 20 boxes of the fish were sent to market from Skyco, Roanoke Island. The steamer *Fish Hawk* caught a specimen about 28 miles off Cape Lookout, August 21, 1902." We have at hand two specimens, each about 15 inches long, taken with hook and line on the blackfish grounds, about 20 miles off Beaufort Inlet, by the *Fish Hawk* in 1913.

A considerable number of young amberfish, ranging from about 10 to 50 millimeters in length, were collected by the *Fish Hawk* in 1914 off Beaufort Inlet and principally on the blackfish grounds. This vessel collected in the same vicinity in 1913 and again in 1915, but no amberfish was taken those two years. Smaller fry were secured near Beaufort Inlet (once inside and several times outside of the inlet) in 1927. Although the towing operations of 1927 were repeated in the same locality and in the same way in 1928 and 1929, no small amberfish was seen during the last two years. The larger fish have not been taken since 1915. Of course, large spawning fish must have visited the coast in 1927 or the fry would not have been present. It may be assumed, from the information at hand, that the occurrence of the amberfish is rather irregular locally, and it is not known that the mature spawning fish enter the inside waters. At Key West, Fla., at least, the amberfish is pelagic in its habits, and it no doubt could be taken oftener off Beaufort Inlet by the employment of proper fishing methods.

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[4] Nearly all the specimens taken locally that are large enough to be pigmented belong to the barred form, *S. zonata* (Mitchill). However, after considerable study devoted to the genus some years ago, it was concluded that *zonata* are young *dumerili* and are so considered here.

The amberfish occurs in sufficient numbers and is important enough to find a separate place in the statistical records of the United States Bureau of Fisheries in Florida only, where 20,675 pounds were marketed in 1927. This fish is rather common at Key West, Fla., during the winter and is taken by trolling. It is considered a good game fish there, and individuals weighing from 50 to 70 pounds are not uncommon. The maximum weight attained is about 100 pounds.

The adults of this species are elongate shapely fish with somewhat compressed bodies. The soft dorsal and the anal fins are long, the former having 30 to 36 rays and the latter 19 or 20, and they are not followed by a detached finlet, as in some of the related species. (See *Decapturus punctatus*, p. 453.) The lateral line has a long, low arch anteriorly and has no bony scutes in the straight portion, as in many related genera, although a keel is present in the adult. The gill rakers are well developed but rather few in number—only 11 to 14 being developed on the lower limb of the first arch. Large individuals are amber colored from which the animal derives the name—amberfish. The young—that is, fish ranging from about 30 to 325 millimeters (1.25 to 13 inches) in length—are bluish-brown above and silvery on the sides, with black bars. The black bars in fish 13 inches or so in length when present in life are not especially distinct and generally fade quickly after death.

SPAWNING

The literature consulted contains nothing relative to reproduction in this species. No ripe fish were seen during the investigation. However, a female, 13 inches long, taken in May, 1915, has the ovaries somewhat distended and probably would have spawned within a few months. This shows that, although the fish reaches a large size, if correctly determined, it may be sexually mature at a length of only about 13 inches. Two larger specimens (15 inches long) taken on the blackfish grounds in September, 1913, have the sexual organs entirely collapsed as if spawned out recently. The eggs, if taken, were not recognized. Small young, ranging from 4 to 12 millimeters in length, were taken in August (1914) and September (1927). While the data are very incomplete, they do show that the spawning season on the coast of North Carolina occurs during the summer, probably from June through September. (See p. 463.) The fact that the fry were taken near Beaufort Inlet during only one season out of three, during which systematic collecting was carried on, seems to show that spawning does not occur there regularly.

DESCRIPTIONS OF YOUNG

Young Seriola are dark in color at a very early age, as seen with the unaided eye, this dark color being due to dark chromatophores variously distributed over the body. The mouth is large and oblique, and the body very early resembles in the general shape that of the adult, specimens 7 millimeters long already being elongate, shapely fish. Unfortunately no specimens of lengths between 14 and 30 millimeters are at hand and, therefore, the development of the intermediate sizes can not be traced at this time.

Specimen 2.9 millimeters long.—The larva at this size is quite compressed, the head is deep, the mouth is slightly superior and strongly oblique, and a very pronounced angle in the ventral outline of the head is formed at the joints or hinge of the mandible. The eye is small for so young a fish and is scarcely longer than the snout. The abdomen is moderately prominent, and the vent is situated near mid-body length. The dorsal profile is quite convex, except for a slight concavity just in front of the eye. The tail tapers gradually and ends in a sharp point. Pectoral fin folds are rather prominent but no ventral fin folds are in evidence. The vertical fin folds either have been torn away or are very low. The specimen is rather dark in color and the only pigment spots evident in a preserved specimen are a few indefinite ones on the ventral outline. (Fig. 73.)

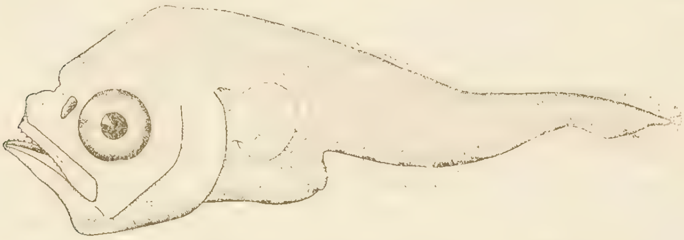

FIGURE 73.—*Seriola dumerili.* Drawn from a specimen 2.9 millimeters long

Young of this size resemble *Decapterus punctatus* somewhat; but the head is not quite as deep in comparison with the body, the snout is not curved upward to the same extent, the eye is proportionately much smaller, preopercular spines are wanting (although present at a somewhat larger size), and fin development has not progressed quite as far. (Compare figs. 68 and 73.) Another distinction is the absence of color markings along the dorsal outline in Seriola.

Specimens 5 millimeters long.—The body remains quite compressed as in smaller specimens. However, anteriorly it is not as deep as previously in proportion to the total length, and the tail, especially distally, is much deeper. The mouth is less strongly oblique, and the sharp angle at the joints of mandible, present in smaller specimens, has disappeared, the ventral outline of the head now becoming evenly convex. Fin rays are not yet very evident, except in the caudal fin. The notochord extends prominently into the upper part of the caudal fin giving the tail a decided heterocercal appearance. Pigmentation in the most distinctly marked specimens consists of a very narrow dark lateral stripe in addition to some large dark chromatophores irregularly distributed over the body. In some specimens the markings are much more diffuse than in the specimens described. (Fig. 74.)

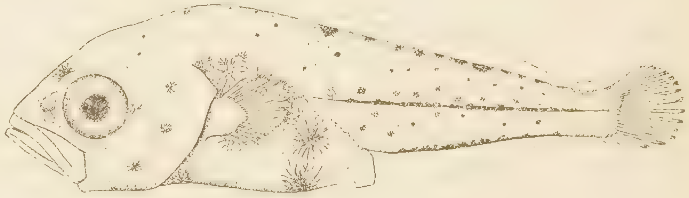

FIGURE 74.—*Seriola dumerili.* Drawn from a specimen 4.7 millimeters long

The absence of preopercular spines, the more regular dorsal outline of the head, and the less strongly oblique mouth distinguish this species from the scad at this size. The large black chromatophores on the side of the abdomen behind the base of the pectoral, too, are helpful, especially since the other color markings are largely similar to those of the scad of the same size.

Specimens 6 millimeters long.—The fish at this size have comparatively large spines on the preopercular margin (which disappear at a somewhat larger size).

Ventral fin folds now are slightly in evidence. The rays in the soft dorsal, caudal, anal, and pectorals are becoming differentiated, the ray development having progressed somewhat further in the pectoral and caudal fins than in the other fins mentioned. The notochord still is visible in the upper part of the base of the rounded caudal fin, but the tail has lost much of its heterocercal character possessed at a somewhat earlier stage. The spinous dorsal still remains largely undifferentiated. Pigmentation is more diffuse than in smaller fish, although some large and distinct chromatophores remain present much as in 5-millimeter fish. A dark lateral stripe is present on most of the caudal length of the body. Then there is also a concentration of color under the base of the dorsal and anal fins. We have specimens preserved since 1914 which are entirely without dark pigment. It is probable, though, that these fish have faded and that the general dark color described in the foregoing lines is normal (Fig. 75.)

The cluster of large, black chromatophores now present at the nape is of much value in recognizing amberfish of this size. This is especially helpful since the other color markings are largely similar to those of the scad of the same size. This cluster of black chromatophores persists until a length of at least 14 millimeters is attained. At that size fin rays are developed and identification may be based largely on adult characters.

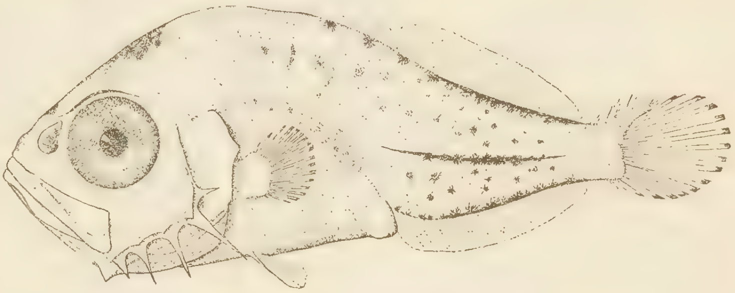
FIGURE 75.—*Seriola dumerili.* Drawn from a specimen 5.7 millimeters long

Specimens 10 millimeters long.—The body is regular in outline, elongate, compressed, and shaped much as in the adult, except that it is less robust. The fins are all fully differentiated and the soft rays are well developed. It is still difficult to enumerate the rays in the dorsal and anal, because of the crowded condition. The anal spines are short and distinct. The spines in the first dorsal, however, are not fully differentiated and the fin, although connected with the second dorsal, is distinct because it is lower. The caudal fin, round in somewhat smaller fish, has an almost straight margin at this size. In the specimens at hand, preserved in 1914, the body is quite dark brownish in color with scattered darker chromatophores. The dark lateral stripe or line of smaller fish has become less distinct and the concentration of black chromatophores at the base of the dorsal and anal fins are no longer pronounced. The dorsal surface of the head is profusely dotted with black.

Specimens 12 to 14 millimeters long.—The changes since a length of 10 millimeters was reached are not pronounced. At a length of 12 to 14 millimeters the rays of the dorsal and anal fins, although crowded, have become distinct enough for enumeration, and the caudal fin is decidedly concave. Preopercular spines are still prominent although proportionately smaller than in somewhat smaller fish. In specimens stained and mounted the vertebræ may be fairly accurately enumerated, the number being 11+14 to 16. This count agrees fairly well with the single adult dissected which had 10+14 vertebræ. The last caudal vertebra (hypleural) in 12-millimeter fish is not yet fan shaped as in the adult, for it is pointed and curved upward distally, therefore retaining in a measure the heterocercal character of younger fish. The color remains essentially as in 10-millimeter fish. (Fig. 76.)

Specimen 30 millimeters long.—A single specimen of this size is at hand. It does not differ greatly in shape from specimens 12 to 14 millimeters long. Preopercular spines, large and prominent in fish ranging from 6 to 14 millimeters in length, are missing and the preopercular margin now is entirely unarmed. The dorsal spines remain rather short but are pungent. The first two anal spines are well separated from the rest of the fin and are short and strong. The lateral line with distinct pores is fully developed and scalation is complete. Dark bands (six in the specimen at hand) apparently are just forming, for they are not nearly as distinct as in larger specimens. The bands or bars plainly are the result of the concentration of the dark chromatophores already present in much smaller fish. The bars are all vertical, except the first one which extends obliquely backward from the eye to the occiput. Dark chromatophores are sparingly distributed over the body between the crossbars. No trace of the dark lateral band or line, prominent in smaller fish, remains. (Fig. 77.)

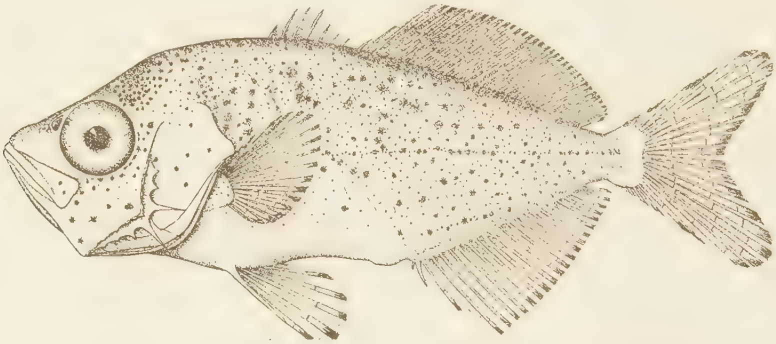

FIGURE 76.—*Seriola dumerili.* Drawn from a specimen 14 millimeters long

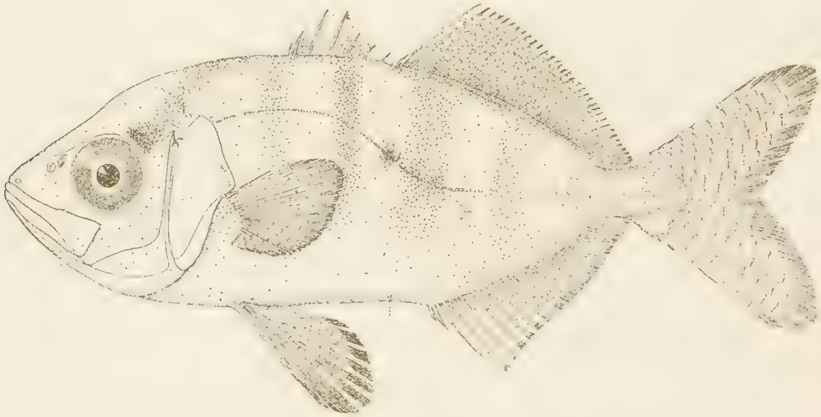

FIGURE 77.—*Seriola dumerili.* Drawn from a specimen 30 millimeters long

Specimens 40 millimeters long.—The difference between the 30-millimeter specimen and those that are 40 millimeters long is not pronounced. The caudal fin is somewhat more deeply forked, and the dark crossbars are more sharply outlined, and rather narrower and darker. The number of bars present in three specimens at hand of this size vary from 6 to 8. (Fig. 78.)

Specimens 110 millimeters long.—The difference between specimens of this size and those 40 millimeters long is comparatively slight. The body remains quite strongly compressed, much more so than in specimens 13 inches long and, of course, very much more compressed than in large fish. The caudal fin is somewhat more deeply forked than at a length of 40 millimeters, yet it is not deeply lunate as in the adult. The ventral fins at this size, as in smaller fish, reach the vent, whereas in large fish they reach only about a third of the distance from their insertion to the vent. A slight keel is evident in the posterior part of the lateral line, which, although lower and less pronounced, corresponds with that of the adult. The upper parts of the body are brownish in preserved specimens and the sides are largely silvery, which in general corresponds with the color of the adult. However, the body is still crossed with several (about 6 to 8) dark brown or black bars, extending on the dorsal and anal fins, which are wanting in the next larger size at hand, namely, specimens 13 inches long. It may be noted, however, that the larger fish had dark bars in life which quickly faded after death.

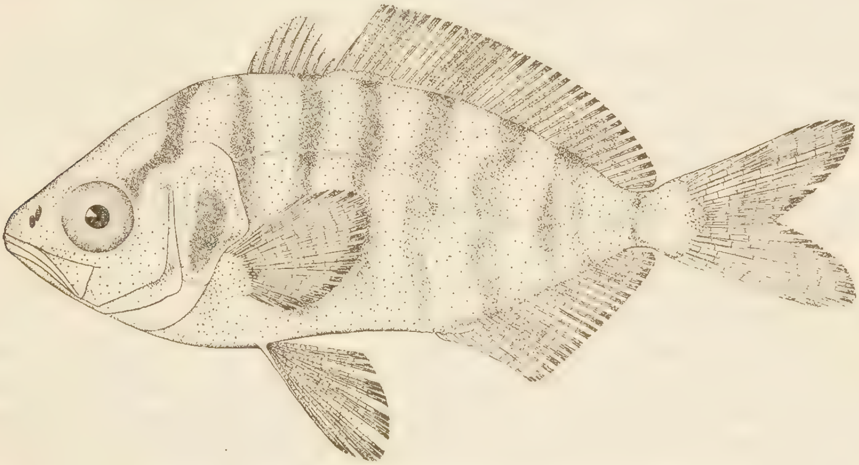

FIGURE 78.—*Seriola dumerili*. Drawn from a specimen 40 millimeters long

Although specimens 110 millimeters (4.4 inches) long differ in many respects from larger fish, as shown in the foregoing paragraph, sufficient adult characters are developed to make identification comparatively easy.

DISTRIBUTION OF YOUNG

Fry ranging from a little less than 3 and up to 10 millimeters in length were taken in 1927 from June 28 to September 24. Other specimens, ranging from about 6 to 10 millimeters in length, were taken by the *Fish Hawk* in 1914 on August 10, 11, and 12. It is evident from the collections of fry, totaling about 75 in number, that spawning takes place during the summer—probably from June through September—for the smallest fry in the collection (2.9 millimeters long) was taken on September 28, 1927.

Specimens collected by the *Fish Hawk*, so far as the records give this information, were taken at the surface. In fact, no nets suitable for catching the fry on the bottom seem to have been used. In the collections made near Beaufort Inlet in 1927, in an equal number of bottom and surface hauls, made simultaneously with two 1-meter townets, the fry were taken 6 times, 2 times at the surface and 3 times on the bottom. This information was missing for the other collection.

All the specimens in the collection, exclusive of one, 5 millimeters long taken just inside Beaufort Inlet, were collected offshore. Those taken by the *Fish Hawk* in 1914 were mostly secured on the blackfish grounds, about 20 miles offshore, and the others taken in 1927 were collected near the shore, at the most not over 15 miles from Beaufort Inlet.

It is evident, therefore, that the fry in the vicinity of Beaufort occur chiefly at sea where spawning no doubt takes place during the summer. Since the young sometimes were taken on the bottom, they probably are not as strictly pelagic as larger fish. Lewis Radcliffe, naturalist aboard the *Fish Hawk* in 1914, states in his notes, "Wherever sargassum weed makes its appearance they (young Seriola) may be found accompanying the weed and at such times are quite common." Elsewhere (p. 459) it is stated that the adult amberfish is caught at Key West chiefly by trolling. It is probable, therefore, that the fry are less strictly pelagic than the older fish.

GROWTH AND FOOD

Almost nothing concerning the rate of growth or the foods eaten appears to be contained in the literature. The present collection obviously is not extensive enough to yield much information on these subjects. Therefore, these phases of the life history of the amberfish remain for future investigation.

PARALICHTHYS DENTATUS (Linnæus) and PARALICHTHYS ALBIGUTTUS, Jordan and Gilbert. Summer flounder; southern flounder

Three nominal species of summer flounders,[5] namely, *Paralichthys dentatus* *P. albiguttus*, and *P. lethostigmus*, are recorded from Beaufort, N. C. However, the present writers are unable to separate the representatives of this genus, occurring locally, into more than two groups (species ?), and not infrequently individuals are seen that are confounding and difficult to identify with either one of the groups into which most specimens are separable. The characters employed in identifying adult summer flounders, namely a combination of gill-raker and fin-ray counts and color markings, are not all developed in the young, or at least are so indefinite that they can not be seen clearly until a considerable size (about 20 to 25 millimeters, or even much larger for color markings) is attained. No characters have been found by means of which the young can be separated into species until the adult characters mentioned above are developed. It is for this reason that we are obliged to treat all the small Paralichthys at hand as one group.

Although this paper is not intended to give a taxonomic account of the flounders, it seems desirable to show the close relationship of the locally represented forms as a guide to future investigators, in order that the reader may understand the difficulty involved in identifying these flounders, also to show more clearly why the young are treated as a single group in this paper.

Considerable time was devoted to the study of the adults for the purpose of ascertaining definitely the number and relationship of the species represented and with the view of finding characters that could be used in identifying the larvæ. In the latter object we failed; and as to the former, we found bewildering variations but no third species. In other words, two species, with certain doubtful intermediate as well as extreme specimens, certainly are present. One of these unquestionably is

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[5] These fish are known locally only as "flounders." The designation "summer flounder" is used in the northern part of the range of Paralichthys in order to distinguish these fish from the "winter flounder" *Pseudopleuronectes americanus*. These designations are used in this paper for the sake of convenience and to avoid the frequent repetition of the scientific names.

dentatus, while the other remains in doubt. We provisionally use for this entire group the name *albiguttus*, which is older than *lethostigmus*, because of the possibility that a further study, especially of specimens from the type localities, Pensacola and Jacksonville, Fla., may show the two to be identical. In which case *albiguttus*, having priority, would stand.

The most reliable character for separating the two locally represented forms which are recognized by us, is the number of gill rakers present on the lower limb of the first arch. That is, *dentatus* nearly always has a higher number of gill rakers than *albiguttus*—the usual range for the first-named species being from 14 to 17 and for the latter 8 to 12. However, some overlapping occurs between the two ranges given, for some specimens which evidently are *dentatus* have only 13 or occasionally only 12 gill rakers, whereas specimens, which appear to be *albiguttus*, sometimes have 12 and rarely 13 gill rakers. (See fig. 79.) The length and shape of the gill rakers generally are of help in separating the specimens in which the counts overlap, for *dentatus* has longer, more slender and smoother gill rakers which are equal to one-half to two-thirds the diameter of the eye, whereas those of *albiguttus* usually are notably shorter, coarser, and dentate.

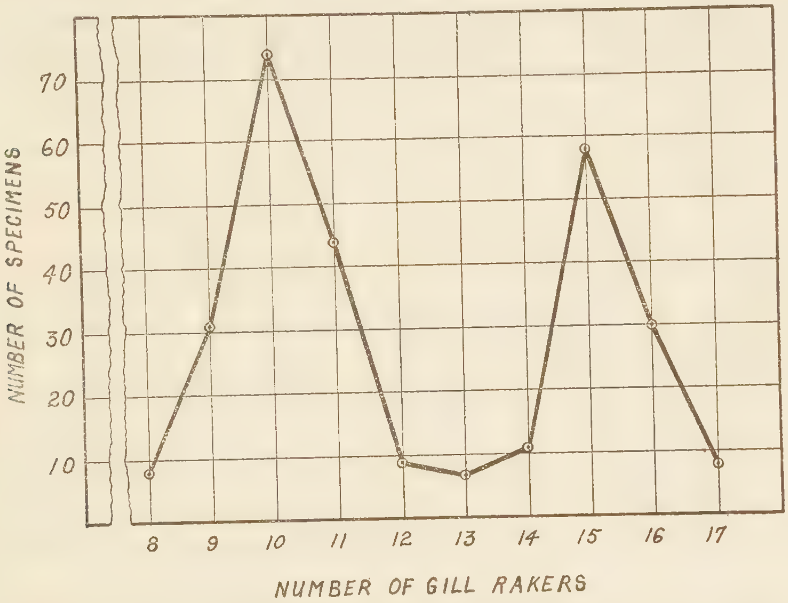

FIGURE 79.—Frequency distribution of gill rakers on the lower limb of first arch in 277 specimens of Paralichthys. Graph based on Table 11

TABLE 11.—*Frequency distribution of dorsal rays, anal rays, and gill rakers on the lower limb of the first arch, of respectively 277, 249, and 277 specimens of Paralichthys*

DORSAL RAYS

Number	Frequency	Number	Frequency	Number	Frequency
72	2	80	19	88	13
73	5	81	19	89	29
74	7	82	9	90	8
75	24	83	19	91	3
76	13	84	6	92	4
77	15	85	8	93	6
78	10	86	15	94	----------
79	16	87	25	95	2

TABLE 11.—*Frequency distribution of dorsal rays, anal rays, and gill rakers on the lower limb of the first arch, of respectively 227, 249, and 277 specimens of Paralichthys*—Continued

ANAL RAYS

Number	Frequency	Number	Frequency	Number	Frequency
54	2	60	16	66	21
55	4	61	16	67	18
56	13	62	5	68	29
57	20	63	6	69	17
58	14	64	12	70	15
59	22	65	16	71	3

GILL RAKERS

8	8	12	9	15	58
9	31	13	7	16	30
10	74	14	11	17	8
11	44				

Correlated with the high number of gill rakers in *dentatus* is a high fin-ray count for both the dorsal and anal. While there is much overlapping between the two species, the average differences are pronounced. The range in the dorsal rays for *dentatus* in 107 specimens enumerated is 80 to 95 with an average of 87.3 rays. The range for the rays in this fin for *albiguttus* is much greater, reaching from 72 to 95 (therefore occupying the entire range of *dentatus*, as well as extending far below it) in the 173 specimens enumerated, but the average is only 79.5. The range in the number of rays in the anal in *dentatus* is 60 to 71 in 95 specimens enumerated and the average is 67.1. In 148 specimens of *albiguttus* the range again is much greater (therefore extending through the entire range of *dentatus* and much lower), reaching from 54 to 71, with an average of 60.7 rays.

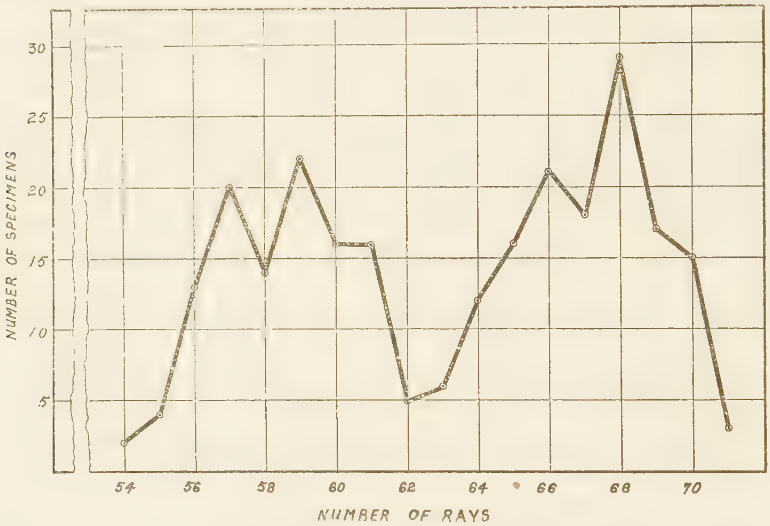

FIGURE 80.—Frequency distribution of anal rays in 249 specimens of Paralichthys. Graph based on Table 11

The extremely great range in the number of fin rays in *albiguttus* suggests that two species may be confused, and it is on this character, chiefly, that the two nominal species *albiguttus* and *lethostigmus*, have been held to be separate and distinct. However, as already indicated, the large number of specimens of Paralichthys examined with respect to the dorsal and anal rays, give no indication of a third species, for when the counts are plotted, as to frequency (see figs. 80 and 81), two modes are evident, for the anal, but not a third one, and no definite modes are shown for the dorsal. The width of the interorbital, too, has been used as a distinguishing character. The variations in the interorbital width are extremely great. The writers are unable, however, to find any correlation between this character and fin-ray counts, and it is believed that the differences probably are only individual variations.

Color markings generally are helpful in separating *dentatus* from *albiguttus*, yet they are not infallible and must not be relied upon too strongly. Usually *dentatus* bears ocellated spots, the three posterior ones being the most distinct. Furthermore, they form an almost perfect equilateral triangle. One of the three ocellated spots is situated on the lateral line and forms the anterior apex of the triangle, and the other two spots, respectively, are situated under the bases of the dorsal and anal and in each case about twice the diameter of the eye from the posterior end of the fins. However, not infrequently the ocellated spots are missing, and specimens of *dentatus* resemble *albiguttus* in color. Rarely the reverse is true, for now and then specimens are seen with definite ocellations, which upon the examination and enumeration of the gill rakers and fin rays appear to be *albiguttus*.

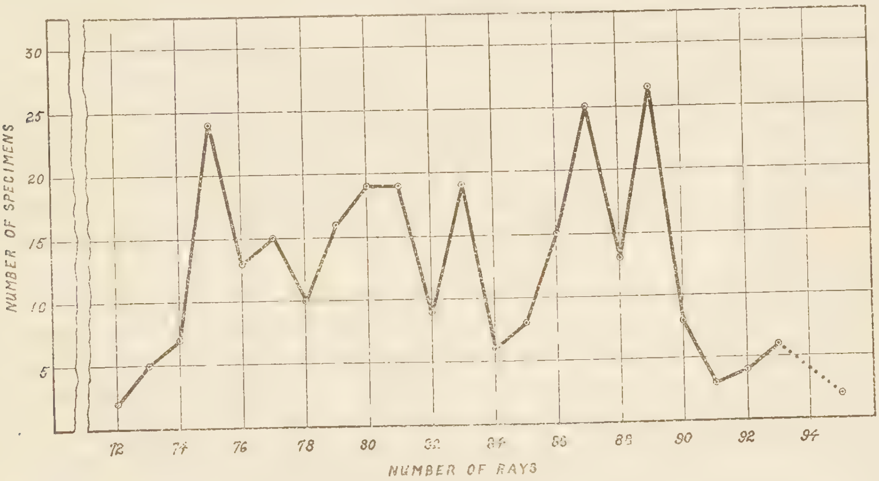

FIGURE 81.—Frequency distribution of dorsal rays in 277 specimens of Paralichthys. Graph based on Table 11

It is evident from the foregoing discussion that the separation of the local species of summer flounders, even with adult specimens, sometimes is difficult. It is not surprising, therefore, that the young (larvæ) are even more difficult and, according to the present studies, inseparable.

The species of the genus Paralichthys known as summer flounders, or southern flounders are recorded from the Atlantic coast of the United States from Maine to Texas. *P. dentatus* ranges farthest northward and is recorded from Maine (occurring only as a straggler north of Cape Cod), and it probably ranges to Florida, its southernmost range not having been definitely determined. The other locally represented form has been recorded by several authors under the name *lethostigmus* from as far north as New York. However, Fowler (1906, p. 395), who states that *dentatus* is the most important flounder on the coast of New Jersey, does not record any other species of Paralichthys from that State. Hildebrand and Schroeder (1928, pp. 165–167), who examined large catches of Paralichthys from Chesapeake Bay, found *dentatus* only, notwithstanding that an earlier author (Smith, 1907, p. 388) had reported *lethostigmus* as common in Chesapeake Bay. The northernmost records of *lethostig-*

mus, therefore, appear to be in need of verification. Whether one or two species are represented on the Gulf coast seems to us uncertain and in need of further study. It is impossible to give at the present time the southernmost range of the local form, which is referred to in the present paper as *albiguttus.*

The relative abundance and economic importance of the two or more species of summer flounders inhabiting the Atlantic coast of the United States from New York to Texas is not known, as the fish are not separated in the market because of their close similarity and statistical reports treat them as a single species. Furthermore, in Chesapeake Bay and northward to New York the winter flounder, *Pseudopleuronectes americanus*, enters into the catch which is listed simply as "flounders" in the statistical reports of the United States Bureau of Fisheries. The bulk of the catch, however, quite certainly consists of summer flounders. As the winter flounder does not occur in commercial numbers south of Chesapeake Bay, the catches reported southward from Virginia consist wholly of summer flounders. It is probable, furthermore, that *dentatus* is not included in the catches from the Gulf coast.

The total annual catch of flounders from the Atlantic and Gulf coasts of the United States, reported in the most recent statistical records of the United States Bureau of Fisheries, amounts to 11,775,046 pounds, valued at $711,224. These data are based on the 1926 canvass of the Middle Atlantic States, the 1925 canvass of the Chesapeake Bay States, and the 1927 canvass of the South Atlantic and the Gulf States. North Carolina produced 348,978 pounds, valued at $23,009. Other States with large catches are New York, 7,352,158 pounds (a considerable part of this catch probably consists of winter flounders); New Jersey, 2,921,714; Delaware, 66,040; Maryland, 118,078; Virginia, 1,581,817; Florida, 131,104; Mississippi, 92,930; and Texas, 77,580.

The summer flounders are not as numerous in the vicinity of Beaufort as several other species of fishes. However, they are of much commercial importance, for they are caught virtually throughout the year, they are well flavored, and always bring a fairly good price. Locally these flounders are caught principally with drag nets, hauled over sandy and muddy bottom. However, quite a few are taken at night by a method known locally as "floundering." A torch with a tank for holding kerosene is placed in the bow of a flat-bottomed skiff. A long pipe with a burner is connected with the kerosene tank in such a way that the burner projects a few feet beyond the bow of the boat, placing the light well in advance of the skiff. Formerly "lightwood" or pine knots were used in a "fire basket" for flounder lighting, but this kind of light has been replaced largely by kerosene torches. On calm nights and on low or a rising tide, skiffs equipped with a torch are slowly poled along the beach in shallow water, while the fisherman keeps a close watch for flounders. The fish often are nearly buried in the sand and only the general outline can be seen and, therefore, they are easily overlooked. When a flounder is found, it is gigged or speared. "Floundering" is successful only on calm nights, as ripples on the water interfere with vision.

The two forms recognized in this paper appear to be about equally common at Beaufort as indicated by market catches examined and by the fact that among 566 fish caught with various collecting gear and brought to the laboratory occurred 289 specimens identified as *dentatus* and 277 identified as *albiguttus*. The size attained also seems to be about equal. The largest specimen of *albiguttus* that we have seen was 29 inches long and weighed 12¾ pounds, whereas the largest specimen of *dentatus* measured by us was 20 inches long. However, somewhat larger ones have been observed in the market. The maximum size attained by *dentatus* is reported as 3 feet and a weight of 10 to 25 pounds. No definite record of the maximum size reached by *albiguttus* (or *lethostigmus*) has come to our notice. It is probable that the 29-inch specimen, mentioned in the foregoing lines, is the largest fish of this form of which there is a definite record.

A slight migration away from the harbor and adjacent estuaries no doubt is made by the summer flounders during late autumn. Both species are present during the winter, although in reduced numbers, and the migration certainly is less pronounced than in the pigfish, spot, croaker, and many other species.

SPAWNING

Summer flounders with roe have been observed infrequently during the present investigation. A few female *Paralichthys albiguttus* with large roe were seen in October and November and a few *P. dentatus* in November with one in February. However, no ripe, or nearly ripe, males were seen. Neither have the eggs been taken, or if secured (which is highly improbable) they have not been recognized.

During two successive autumns adult flounders were confined in aquarium tanks and held throughout the winter. The tanks were furnished with a screened overflow and a small stream of running water from a storage tank into which water from the harbor was pumped daily. It was hoped that the fish would develop roe and cast eggs in the tanks. Although the animals appeared to be healthy and took food (cut fish) regularly, they failed to develop spawn, and our efforts to obtain the eggs for study in this way failed, as did all efforts to obtain them in nature. It seems probable, therefore, that the summer flounders, like the spot, will not spawn in captivity under the conditions provided at Beaufort.

Very small fry, including some slightly under 3 millimeters in length that evidently had been hatched very recently, were taken many times and in considerable numbers, as shown by Table 12. The duration of spawning no doubt is fairly accurately shown by the presence of the larvæ in the collections. However, since two species of flounders very probably are included among the fry (which we are unable to separate), the duration of the spawning season for each species can not be determined. Although the reproductive periods of the two species overlap, as shown by the presence in November of nearly ripe females of both species, it is possible that they do not begin or end simultaneously. However, Table 12 shows only one main uninterrupted period when the larvæ were numerous in the collections, indicating either that the spawning periods of *P. albiguttus* and *P. dentatus* occur simultaneously, or that only one species is represented.

It will be seen from Table 12 that small fry are numerous in the collections only in November and December, notwithstanding that a few were taken in September, several in January and February, and a few more in March, April, and May. These data, then, indicate that some spawning takes place from September to May and that the height of the season occurs in November and December. This period of spawning coincides with the observation of several ripening females in October and November and one in February, as reported in a preceding paragraph.

Spawning probably takes place chiefly, if not wholly, at sea. This conclusion is arrived at from the distribution of the very small fry which were taken much more frequently off Beaufort Inlet than within the harbor, as shown subsequently (p. 474.)

The literature contains very little information concerning the spawning habits of Paralichthys. Hildebrand and Schroeder (1928, p. 166) state that specimens of *P. dentatus* taken in Chesapeake Bay during October had comparatively large gonads.

From this fact and the size of the young secured during the spring and summer, these authors conclude that the eggs quite certainly are cast during the winter.

TABLE 12.—*Length frequencies of 1,151 young summer flounders, indicating that spawning probably begins in September and ends in April or May*

Length in millimeters	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
0–4	10	87	98	14	25	6	3	1	----
5–9	3	270	237	39	45	17	8	5	----
10–14	----	8	97	60	44	13	3	----	----
15–19	----	----	----	----	3	35	----	----	----
20–24	----	----	----	----	----	9	----	----	----
25–29	----	----	----	----	----	1	----	----	----
30–34	----	----	----	----	----	----	1	----	----
35–39	----	----	----	----	----	----	----	----	1
40–44	----	----	----	----	----	----	1	----	1
45–49	----	----	----	----	----	----	----	1	----
50–54	----	----	----	----	----	----	----	----	1
55–59	----	----	----	----	----	----	----	2	1
60–64	----	----	----	----	----	----	----	----	----
65–69	----	----	----	----	----	----	----	----	----
70–74	----	----	----	----	----	----	----	----	1

DESCRIPTIONS OF YOUNG

Ample specimens are at hand to show all the stages in the development of the larvæ. The following descriptions and drawings have been prepared with the view of conveying to the reader a fair idea of the important stages in their development.

Specimens 2.5 millimeters long.—The recently hatched fish is compressed, deep anteriorly, and the caudal portion is relatively long and slender ending in a sharp point. At a size of 2.5 millimeters the head is decidedly deflected and proportionately very large, having a prominent hump, situated over and slightly behind the eyes, inclosing the brain. The mouth is large, strongly oblique to nearly vertical, and the joint of the mandible forms a sharp angle with the ventral outline. The visceral mass projects prominently, is loosely attached to the body, and the hind-gut is plainly visible posterior to the main visceral mass. A few very small dark chromatophores are visible along the ventral outline of the caudal portion of the body, and at a slightly larger size they appear on the visceral mass. An interesting structure is the relatively large pectoral-fin fold which becomes proportionately smaller as the fish grows, resulting finally in a comparatively small fin. It is interesting to compare this pectoral-fin development with that of the tonguefish, *Symphurus plagiusa*. The larvæ of the tonguefish, too, have a rather prominent pectoral-fin fold, which, however, disappears entirely at a size of 10 to 12 millimeters. (Fig. 82.)

Specimens of Paralichthys of this size are most readily recognized by the deep, compressed body, long slender tail, and large hump on the head. The row of dark spots, usually present along the ventral edge of the caudal portion of the body, also is helpful.

Specimens 4 millimeters long.—The advancement in the development over the 2.5-millimeter specimen described in the foregoing paragraph is not pronounced. The head in the 4-millimeter fish is slightly less deflexed, the occipital hump is somewhat smaller, and the mouth probably is a little less oblique. The dark chromatophores of the smaller fish have increased in size and number on the abdominal mass, and a few are now present on the back. The eyeball is slightly concave above and below and a little longer than deep in specimens of this size, as well as in smaller and in somewhat larger ones, as shown in the accompanying drawing. The base of a small fin at the nape (more fully developed at a slightly larger size) is just appearing in specimens 4 millimeters long. (Fig. 83.)

The row of dark spots along the ventral edge of the abdomen, mentioned for the smaller stage, is now quite evident and, in combination with black chromatophores on the visceral mass, aids identification. Another recognition mark is the base of a small fin just becoming evident at the nape. This fin develops rays at a slightly larger size, which still later became produced and separate (that is, without interradial membranes) and persist until the right eye crosses the ridge of the head at a length of 10 to 12 millimeters. Through all the stages of the fish intermediate of a length of 4 to about 12 millimeters this fin, therefore, serves as a recognition mark.

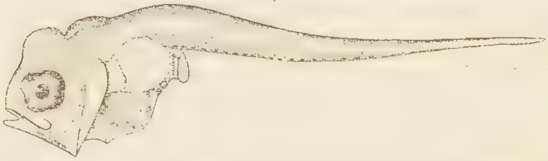

FIGURE 82.—*Paralichthys sp.* From a specimen 2.75 millimeters long

Specimens 6 millimeters long.—At this size the head is quite fully in line with the axis of the body, the occipital hump inclosing the brain, described in the smaller fish, no longer is present and the brain is now inclosed in the cranium through which it is plainly visible. External symmetry remains complete. A decrease in the proportionate depth of the anterior part of the body has taken place. The visceral mass projects less prominently than in the smaller fish described and it is more firmly attached, the body wall having thickened and definitely enveloped it. The small fin at the nape, of which the base only is present in a 4-millimeter specimen, is now well developed. Rays in the caudal fin, below the upward curve of the notochord are just beginning to appear. In pigmentation no changes worthy of note have taken place. Although chromatophores are not shown on the abdomen in the accompanying drawing, they are present in some specimens of this size. (Fig. 84.)

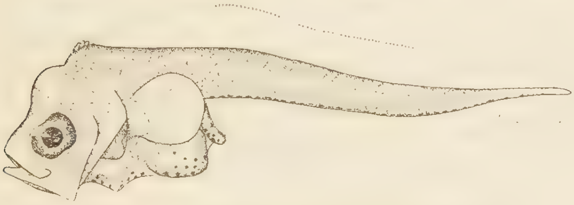

FIGURE 83.—*Paralichthys sp.* From a specimen 4 millimeters long

Specimens 7 millimeters long.—The fish is becoming more definitely compressed. This is especially true of the caudal portion of the body, which also has increased greatly in depth since a length of 5 to 6 millimeters was attained. Symmetry no longer is complete, as the right eye is situated slightly higher than the left one. A notable depression in the dorsal profile of the head is now present over the eyes. The mouth is less strongly oblique than in smaller specimens. The caudal fin is rather fully developed and rays are appearing in the dorsal and anal fins, and the small fin at the nape, described in somewhat smaller specimens, is merging with the long dorsal. Pigmentation remains much as in 5 and 6 millimeter fish, except that the markings have become more distinct and a dark spot is present at the occiput near the origin of the dorsal. (Fig. 85.)

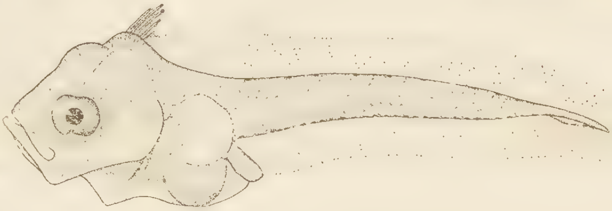

FIGURE 84.—*Paralichthys sp.* From a specimen 5.5 millimeters long

Specimens 8 millimeters long.—The fish has become much more compressed and "flounder shaped." The normal number of fins, including ventrals, are present. The finlet at the nape, described for smaller fish, has become definitely merged with the dorsal. A few of its rays are longer and larger, however, than the other rays of the dorsal. The right eye has made considerable progress in its migration, for it is near the dorsal ridge at the greatly depressed point in the profile described in the 7-millimeter specimen, and it is in part visible from the left side. Pigmentation has not changed greatly from that of somewhat smaller fish. The markings are only a little more definite and a few chromatophores are now present on the sides of the body. At this size the color markings are identical and equally developed on both sides of the fish. (Fig. 86.)

Specimens 11 millimeters long.—The right eye is situated on the ridge of the head and is "looking up." Specimens of this size were stained, cleared, and mounted, making the vertebræ, or at least their projections, visible. A range from 9 or 10+26 to 30 was found in the number of vertebræ in 17 specimens enumerated. The number of vertebræ is not a distinctive character, however, as the number present is almost identical with several other locally represented species of flounders. Pigmentation has progressed rather rapidly on the left side since a length of 8 millimeters was attained, and it is no longer identical on both sides, as the markings of the right side remain as in the somewhat smaller fish described in the foregoing paragraph. The new chromatophores of the left side are principally so placed as to suggest crossbars. The upward curve of the notochord, prominent in smaller specimens, is scarcely visible at this size, and the tail has lost it heterocercal appearance. (Fig. 87.)

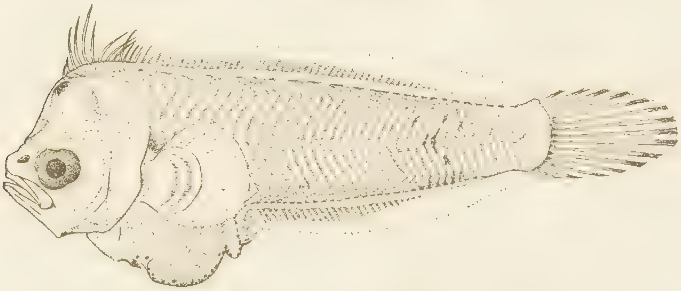

FIGURE 85.—*Paralichthys sp.* From a specimen 7 millimeters long

The fish is now plainly shaped like a Paralichthys, and the fin rays in the dorsal and anal are well enough developed to admit a fairly accurate enumeration. A further aid in identification is the presence of dark chromatophores on the sides arranged so as to suggest crossbars.

Specimens 16 millimeters long. — The form and shape is approaching that of the adult at this size. However, the caudal portion is still a little too slender and the ventral outline has not yet become rounded as in the adult. The chest, with the pelvic bones, is well separated from the gill covers, leaving a vacant space. The right eye is well across the ridge of the head, and both eyes are situated on the left side of the head. Numerous chromatophores are present on the left side, both on the body and on the fins. Many are arranged in clusters, forming diffuse spots. On the blind side a row of dark dots remains along the dorsal and ventral periphera. Although pigmentation has progressed rapidly since a length of 11 millimeters was reached, it is not general. Live fish of 16 millimeters, and considerably larger ones, remain surprisingly transparent and are extremely difficult to see and no doubt

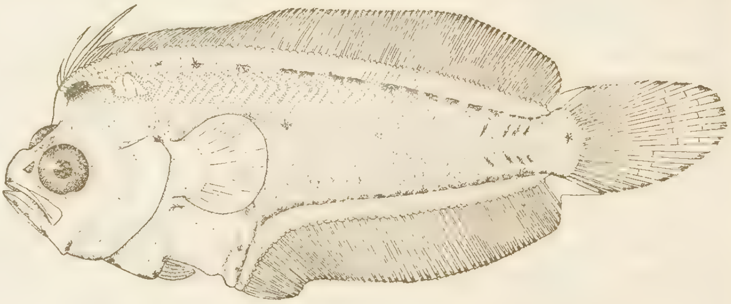

FIGURE 86.—*Paralichthys sp.* From a specimen 8 millimeters long

frequently are overlooked in collecting nets. The gill rakers on the lower limb of the first arch can be fairly accurately enumerated at this size and, as the specimen from which the drawing was made appears to have only about 10, it probably is *P. albiguttus*. (Fig. 88.)

Specimens 26 millimeters long.—At this size the shape of the body is very nearly as in the adult. The ventral outline, however, is not yet as evenly rounded as it will be later. The eyes are situated virtually as in the adult, the upper (right one) being a little in advance of the lower one. Although still proportionately larger than in grown fish, a notable proportionate decrease in size has taken place since a length of 16 millimeters was reached—the diameter being about equal to the length of the snout, whereas it was much longer than the snout in 16-millimeter specimens. The body, exclusive of the head, is rather fully scaled. Pigmentation has become quite general on the left side, while only a few dark dots along the dorsal and ventral periphera of the body remain on the blind side. The concentration of chromatophores on the "eyed side" has increased, and rather definite dark spots are present on the body and on the vertical fins. The specimen drawn has only 9 gill rakers on the lower limb of the first arch and, therefore, quite probably is *P. albiguttus*. (Fig. 89.)

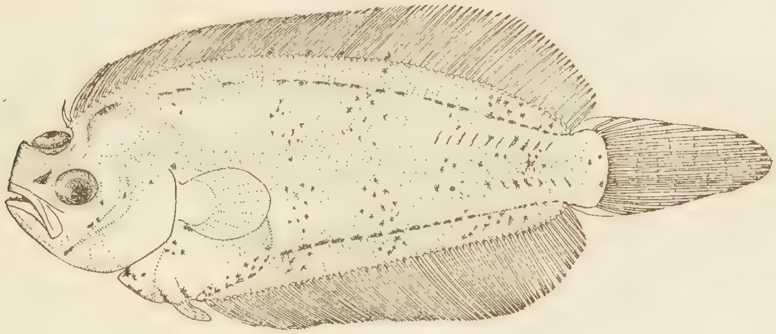

FIGURE 87.—*Paralichthys sp.* From a specimen 11 millimeters long

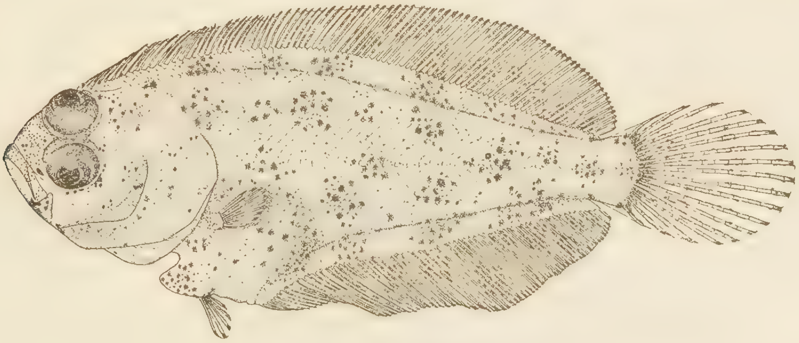

FIGURE 88.—*Paralichthys albiguttus* (?). From a specimen 16 millimeters long

Specimens 77 millimeters long.—The shape and form of the adult has been fully acquired; the body is completely scaled, and pigmentation is general. The eye has decreased further in proportionate size, and the mouth has acquired the characteristic upward and forward curve. The color at this size is very variable as in the adult, some specimens being almost plain brownish with traces of dark spots. Others are variously speckled and spotted. The particular specimen drawn, which is *Para-*

lichthys dentatus, is a profusely spotted one, having the typical ocellations of that species. (Fig. 90.)

DISTRIBUTION OF YOUNG

Very small fry, 3 millimeters and under in length, were taken only at sea. Somewhat larger fish up to 5 millimeters in length, although taken within the harbor near Beaufort Inlet a few times, certainly are much more numerous outside. Sizes ranging from 6 to 10 millimeters in length were taken both inside and outside, and judging from the number of specimens contained in the collections they seem to be about equally distributed over the entire area in which collections were made, extending from 12 to 15 miles offshore through Beaufort Harbor and near-by portions of the adjacent sounds, and 6 to 7 miles into the estuaries of Newport and North Rivers.

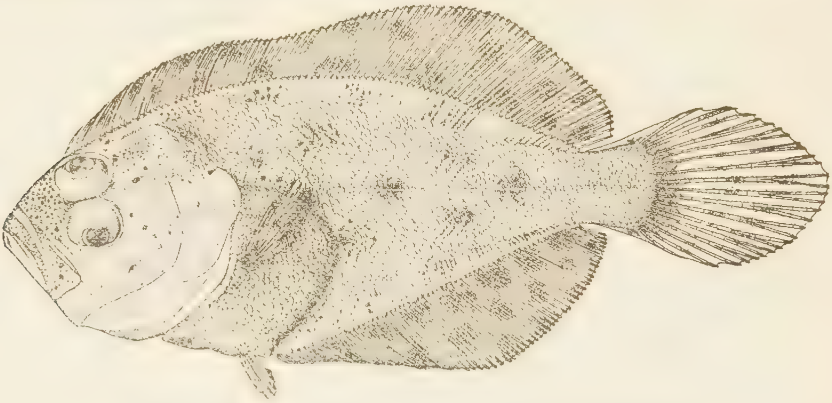

FIGURE 89.—*Paralichthys albiguttus*. From a specimen 26 millimeters long

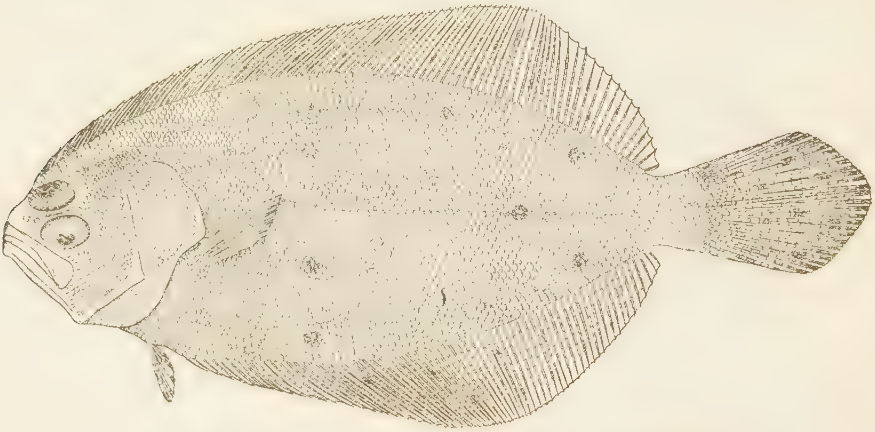

FIGURE 90.—*Paralichthys dentatus*. From a specimen 77 millimeters long

Fish exceeding a length of 10 to 12 millimeters are rarely taken with 1-meter townets. Since much less collecting with apparatus designed to capture the larger young was done in outside than in inside waters, the comparative abundance of these fish in these areas is uncertain. However, the indications are that young fish ranging upward of 10 millimeters are more numerous inside, and especially in the estuaries, than off Beaufort Inlet. Furthermore, a migration toward brackish and fresh-water creeks and ditches of fish ranging upward of about 15 millimeters, is indicated by limited collecting in such waters. It is quite certain that the larger young ranging from about 15 to 100 millimeters or so in length, are scarce in those areas where the smaller ones are obtainable in considerable numbers and that they must be sought elsewhere. In the light of our present limited information, it seems probable that the larger young may live principally in the brackish and fresh water creeks and ditches.

The distribution of the young over time and season has been shown in part under the head "Spawning" (p. 469). Small fry, ranging from about 2 to 4 millimeters in length were taken from September to May but were numerous only during November and December. Somewhat larger fish, 5 to 14 millimeters long, were common in the collections from November to March. Larger young, ranging from 15 to 25 millimeters in length are comparatively scarce and were taken only in February and March. Still larger ones, ranging upward to about 125 millimeters are sparingly represented and fish coming within this range were taken only in April, May, and June.

Adult Paralichthys, of course, live almost wholly on the bottom. It is evident from the present investigation that the fry also inhabit the bottom, for in an approximately equal number of hauls made with two 1-meter townets, hauled simultaneously at the surface and on the bottom, the larvæ were present in 119 bottom and in only 10 surface collections. Since the eggs have not been taken, it is not known, of course, whether they are of the demersal or the pelagic type. It is quite certain, however, that if the eggs hatch at the surface the young go to the bottom very quickly. The rather constant presence on the bottom of recently hatched fry (only 2 to 3 millimeters long, with deflexed heads) and their almost total absence at the surface, suggests that the eggs may be demersal.

It is evident from the foregoing discussion relative to the distribution of the young that spawning very probably takes place exclusively at sea from September to April or May, but principally in November and December. It is indicated, furthermore, that the young move shoreward and into the inside waters at an early age and that at a somewhat later age, still, they enter brackish and fresh water. It is shown, also, that the fry, like the older and the adult fish, live almost exclusively on the bottom.

GROWTH

Insufficient specimens of the proper sizes have been obtained to show the rate of growth, and this part of the life history must remain unsolved until the habitat of the young fish, ranging from about 25 to 125 millimeters in length, is more definitely located and a much larger number of specimens is collected.

Hildebrand and Schroeder (1928, p. 166) working with fish from Chesapeake Bay, where *P. dentatus* alone is represented, state that their specimens indicate a length of 120 to 180 millimeters (4.7 to 7.1 inches) at one year of age, a length of 200 to 250 millimeters (7.9 to 10.2 inches) when 1¾ years old, and around 270 to 280 millimeters (10.6 to 11 inches) when 2 years old. However, these authors had limited data and their results are not conclusive.

The age of these flounders at sexual maturity, of course, can not be given as their rate of growth is not well enough known. The individuals with large roe that have been observed, invariably, were large ones and ranged in length from 16½ to 29 inches. It seems probable that sexual maturity is not reached at an early age if it be true that the fish first must attain a length of about 16 inches, for our meager data do not suggest a rapid rate of growth.

FOOD AND FEEDING HABITS

It has been shown in that section of this paper dealing with the distribution of the young of the summer flounders, that the fry like the larger young and the adults live on the bottom. Since they habitually dwell on the bottom it follows that they must acquire their food there. No study of the stomach contents of small fish has been made during the present investigation. A considerable number of large flounders has been examined, however, and their food consisted almost wholly of fish, supplemented sparingly by crustaceans. Hildebrand and Schroeder (1928, p. 166) report fish as the principal food, supplemented by squids, shrimp, crabs, and Mysis for specimens from Chesapeake Bay.

Flounders frequently are seen in shallow water, partly covered with sand or mud, and in color they resemble the background. That is to say, if the fish happen to be on sand of a light color, for example, the body is light in color and generally profusely speckled and spotted, thereby more closely resembling the sand. However, if the background consists of dark mud the fish are dark and quite uniform in color. In other words, these flounders are able to simulate to a remarkable degree the color and pattern of the bottom. (See Mast, 1916, pp. 177–238, pls. XIX–XXXII.) Thus concealed from easy vision, they lie in wait for their prey. Although generally rather sluggish fish, they are able to dart from their partial concealment with remarkable rapidity to seize their prey, and they strike with great force. These feeding habits of the summer flounders are easily observed by confining the fish in aquarium tanks, for the fish live well and feed readily in captivity. The senior author once kept about a dozen flounders for nearly two years in a tank supplied with a small stream of running water for the purpose of watching their behavior. The fish lost all fear of a person in several months time and would strike at a man's finger when inserted in the tank just as readily as at a minnow. A laborer who was cleaning the tank, for example, suffered a painful injury one day when a fish struck his hand at a moment when he was offguard.

It is of interest to note that this lot of fish, held in confinement for a long time, when finally liberated apparently had lost the sense of self-preservation. The fish were placed in the water on a sandy beach at high tide but failed to follow the water with the receding tide, remaining on the beach where they had settled upon liberation. When it became evident that they would remain there to die, they were placed in deeper water. It is not known, however, whether these animals again learned to cope with nature and shift for themselves or whether they perished. While color and pattern simulation of the bottom and partial concealment in sand and mud no doubt at times serve the fish as protection from enemies, it very probably is far more important as a concealment from its prey until the critical moment comes when it is time to strike.

SYMPHURUS PLAGIUSA (Linnæus). Tonguefish; sole

The tonguefish is known from Chesapeake Bay southward to Florida, occurring on both coasts of the Florida peninsula. It is common to numerous at Beaufort, N. C., but rare farther northward. Hildebrand and Schroeder (1928, p. 178) say, "It is a rare fish in Chesapeake Bay and unknown to most of the fishermen." It seldom attains a length of 7½ inches, and the usual length of adults is only 4 or 5 inches. It has no direct commercial value and appears to enter into the food of commercial fish only occasionally. Therefore, its economic value appears to be very slight.

The fish is readily recognized by its tongue shape from which it derives its common name. The dorsal and anal fins are continuous with the caudal; pectorals are wanting in the adult; and the single ventral that is present is situated on the ventral edge, slightly in advance of the anal. The skin is very tough and slimy. The slime makes the fish very slippery and difficult to hold with the hand. It is thought that the abundance of slime and the toughness of the skin may serve the fish as protection against enemies

The literature, as far as known to us, contains almost nothing concerning the habits and life history of this sole.

SPAWNING

Ripe fish have not been observed at Beaufort, nor have the eggs been taken, or if taken they at least have not been identified. Eggs removed from a ripe, or nearly ripe, tonguefish, taken in Chesapeake Bay on July 26, 1916, have been examined by the present writers. Several different sizes are present, indicating that the eggs are not all cast at one time. The ova before spawning are round, and the largest ones in the specimen examined were only about one-half millimeter in diameter.

Although ripe fish were not observed nor eggs obtained, the spawning season nevertheless has been quite accurately determined by the collection of the fry. During nearly four years, townet collections were made quite consistently at about weekly intervals, with the result that tonguefish fry (5 millimeters and under in length) were taken from the last week of May to the first week of October. The larvæ were taken more frequently and in larger numbers in June than at any other time. It may be concluded therefore, that the spawning season extends from May to October and that it probably is at its height in June. From the distribution of the young, as explained on page 481, it seems rather certain that nearly all spawning takes place at sea.

DEVELOPMENT OF YOUNG

The development of young flatfishes always is interesting. The stages of the tonguefish described and figured in these pages are believed to be complete and comprehensive enough, except for one missing stage, to give the reader a fair idea of the development from a recently hatched larva, only about 2 millimeters long, until the fish virtually acquires all the characters of the adult.

Specimens 2.0 millimeters long.—The body is very deep anteriorly, the caudal portion is comparatively long and tapers posteriorly, ending in a rather sharp point. The forehead is high, with a slight concavity above the eyes. The chin is deep and strongly angled. The abdomen is large and protrudes downward prominently and the coils of the alimentary canal are visible in preserved specimens through the thin walls. The mouth is large, oblique, and extremely close to the relatively large eye. Over the head, or at the occiput, are two long filaments. The notochord is visible almost throughout the length of the body as a pale streak. The pigment present consists of three slightly elongated dark spots situated on the back, over the middle part of the body, and in some specimens a dark line is evident on the ventral edge of the caudal portion at the base of the fin fold. At this size the body externally is entirely symmetrical, the eyes being opposite and equally distant from the mouth. (Fig. 91.)

The strongly protruding visceral mass and the large oblique mouth placed very close to the eye are outstanding characters. However, the most evident recognition mark is furnished by two long filaments on the median line of the occiput. These filaments increase in number with age, some of them becoming bifid, and they persist until a length of at least 10 millimeters is attained. The high number of vertebræ (about 43 to 47), as shown by the muscular rings, is helpful in separating the tonguefish from the other flatfishes of the vicinity of Beaufort.

Specimens 3.0 millimeters long.—The body has increased in depth at this size. The forehead is scarcely as prominent as in a 2-millimeter specimen, the chin is less strongly angled, but the abdomen is larger and protrudes even more strongly. The intestine remains visible through the abdominal walls, as in smaller specimens. The mouth remains close to the eye and strongly oblique. Instead of 2 filaments at the occiput, as in the smaller specimens, 3 or 4 are now present. Indications of fin rays have appeared within the fin fold on the distal part of the tail, and a pectoral fin is becoming visible. The elongated dark spots on the back, described in the 2.0-millimeter specimens, are more evident and more elongated, and in some specimens an indication of a fine dark line between them is present. A finely dotted line is now plainly evident along the ventral edge of the caudal portion of the body. The body remains entirely symmetrical and the slight pigmentation just described is identical on both sides of the fish. (Fig. 92.)

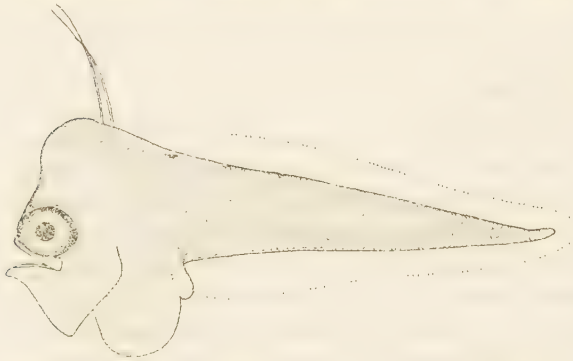

FIGURE 91.—*Symphurus plagiusa.* From a specimen 2 millimeters long

Specimens 5.0 millimeters long.—The caudal portion of the body is much deeper than it is in a 3.0-millimeter specimen, but the anterior portion has decreased in depth and the abdomen protrudes much less prominently. The forehead is now much lower; the eye is proportionately smaller, and the mouth is much farther removed from it. The course of the alimentary canal remains only faintly visible through the abdominal walls. The margin of the opercle is becoming visible, branchiostegals are evident, and the maxillary and premaxillary are well outlined. The filaments on the head have increased still further in number, four to seven now being present. They are unequal in length and in some specimens the longest ones are bifid. Fin rays of the dorsal, caudal, and anal fins are well developed, and the pectoral fin is distinct. Pigmentation differs only slightly from that of a 3.0-millimeter specimen. The notochord remains visible throughout as a pale streak. Symmetry remains perfect in all external characters, except that the vent is situated to the right side of the anterior rays of the anal fin. (Fig. 93.)

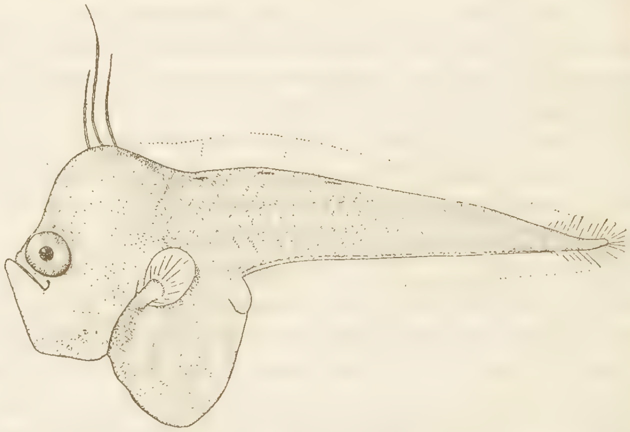

FIGURE 92.—*Symphurus plagiusa.* From a specimen 2.7 millimeters

Specimens 7.0 millimeters long.—Development has proceeded regularly since a length of 5.0 millimeters was attained but the changes are not pronounced. The body has become more shapely; that is, it has acquired more nearly the form of the adult. The abdomen still protrudes quite prominently and, through its walls, the alimentary canal remains faintly visible. The filaments on the head are proportionately shorter and are becoming definitely merged with the dorsal fin, forming the anterior rays thereof. Color markings are less distinct than in smaller specimens. The eyes are proportionately much smaller in size and symmetry no longer is complete, for the right eye is about one-half an eye's diameter higher than the left one and also slightly in advance of it. The relative position of the eyes can be seen plainly because of the transparency of the head. In all other respects the symmetry apparently remains as complete as in 5-millimeter specimens. A fairly accurate count of the vertebræ may be made at this size by staining and clearing specimens. In 11 specimens, 7 millimeters in length and somewhat larger ones, the body vertebræ were constantly 9 and the caudal ones ranged from 34 to 38. Since no other flatfish known from the vicinity of Beaufort has such a large number of caudal vertebræ this character is distinctive. (Fig. 94.)

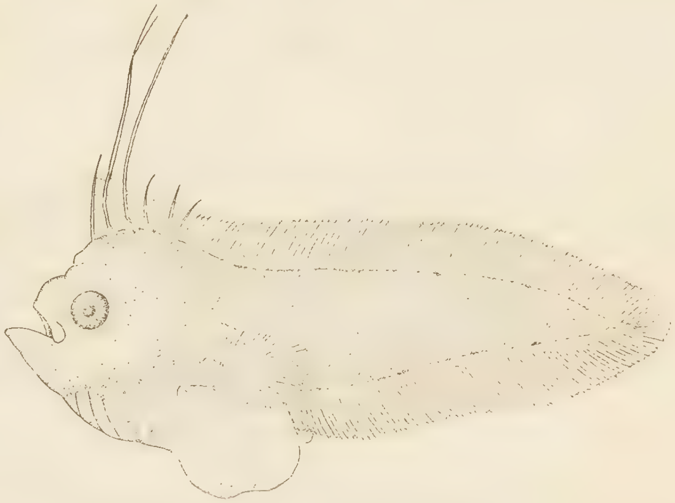
FIGURE 93.—*Symphurus plagiusa*. From a specimen 4.75 millimeters long

Specimens 10 millimeters long.—No pronounced differences between fish of this length and those of 7.0 millimeters are evident. The eyes still are on opposite sides of the head, and although the right one is situated higher than the left one comparatively little advancement is evident in this respect over 7.0-millimeter fish. The abdomen still protrudes rather prominently and the body in general is proportionately deeper than in somewhat older fish. A few filaments with bifid tips remain on the head. The mouth is terminal and only a little less oblique, and the characteristic curve of the premaxillaries of the adult is faintly developed. In fin ray and pigment development, no changes of importance are evident. A few scattered, dark spots, however, are present on the posterior part of the body. (Fig. 95.)

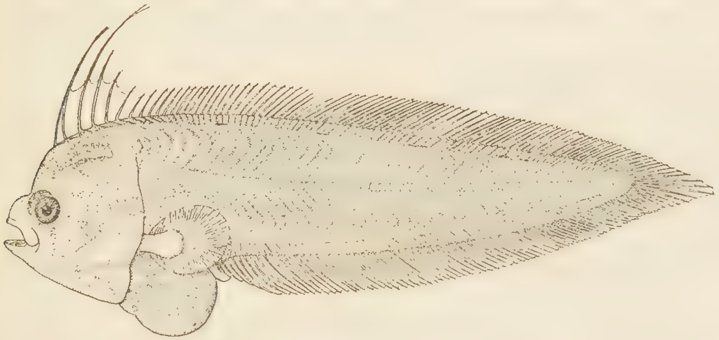
FIGURE 94.—*Symphurus plagiusa*. From a specimen 7 millimeters long. Right eye has begun migration. Its position is indicated in drawing

Specimens 13 millimeters long.—The differences between 10 and 13 millimeter specimens are pronounced. In the larger specimens the eyes are close together on the left side of the head, as in the adult; the abdomen no longer protrudes; the body has definitely acquired the shape of the adult and is completely scaled; the anterior rays of the dorsal fin are no longer filamentous; the rudimentary pectoral fin has disappeared almost completely; a ventral fin in advance of the anal is evident for the first time; the mouth is horizontal and slightly inferior; the premaxillaries have acquired a pronounced curve as in the adult; and pigmentation has become general, distinctive color markings consisting of dark bars. Our material suggests a sudden metamorphosis soon after a length of 10 millimeters is reached or perhaps that no increase in the length takes place during this critical stage. For example, a specimen fully 10 millimeters long still has the eyes on the opposite sides of the head, the right one being situated only a little higher and slightly in advance of the left one; the abdomen protrudes, much as in smaller larvæ; and the anterior rays of the dorsal are still filamentous. An 11-millimeter specimen, on the other hand, has virtually all the characters of the 13-millimeter specimens described in the foregoing lines. It is quite probable, of course, that some variation in the length at which adult characters are acquired occurs among individuals. It is expected, that in some individuals the eyes, for example, will become situated on one side of the head at a somewhat smaller size than in others. Insufficient material is at hand, however, to show the exact variations, for we have comparatively few specimens ranging from 7 to 15 millimeters in length. These specimens also fail to show the complete migration of the right eye to the left side of the head, notwithstanding that one or a few specimens are at hand for each 1-millimeter group, ranging in length from 8 to 15 millimeters (the range in size during which the metamorphosis takes place). In 10-millimeter specimens, as already explained, the migration of the eye appears to have

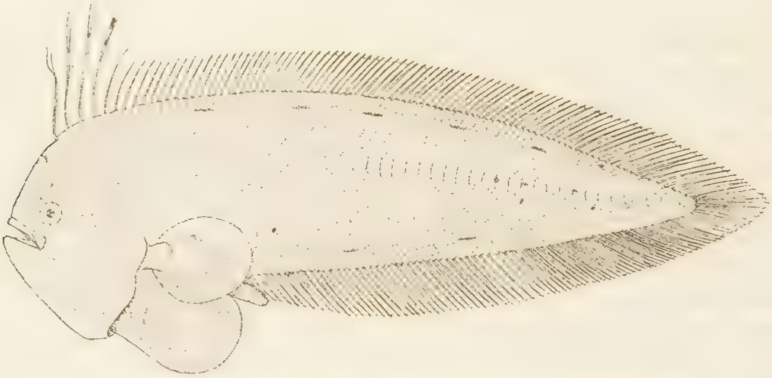

FIGURE 95.—*Symphurus plagiusa.* From a specimen 10 millimeters long

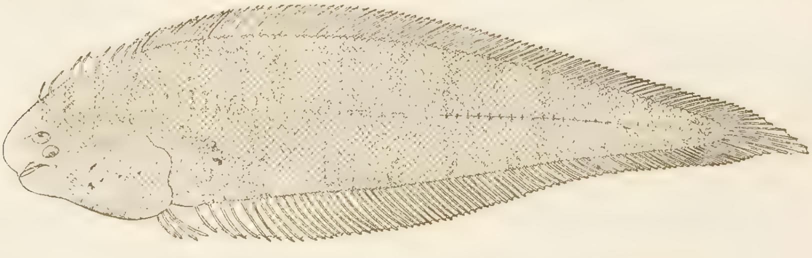

FIGURE 96.—*Symphurus plagiusa.* From a specimen 13 millimeters long

just begun, whereas in an 11-millimeter specimen, and larger ones, it has been completed. (Fig. 96.)

Specimens 35 millimeters long.—The fish has acquired virtually all the characters of the adult at this size. It is proportionately more slender, the depth being contained about 3.5 times in the length, whereas in the adult the depth is contained in the length about 3.0 times. The differences between fish 13 to 35 millimeters long are not pronounced. It is evident, however, that the rays in the anterior part of the dorsal and anal fins have become more crowded in the larger specimens and the characteristic dark bars of the smaller fish sometimes, although not always, become quite indefinite. Considerable variations in color are evident, however, in fish of this size and larger ones; some specimens being quite plain brownish gray, others paler gray, and some are without spots or bars, whereas others are indefinitely barred and variously specked or spotted. Fish 35 millimeters in length, and even smaller ones, are readily recognized by anyone familiar with the adult. (Fig. 97.)

DISTRIBUTION OF YOUNG

Small fry, 5 millimeters and under in length, were taken in only 2 collections made within the harbor, whereas they occur in 46 collections made off Beaufort Inlet, some of the stations at which the collections were made being as much as 12 to 15 miles offshore. Somewhat larger fish were taken a little more frequently within the harbor, but they remain more numerous at sea. It may be concluded from the distribution of the fry that spawning takes place principally at sea.

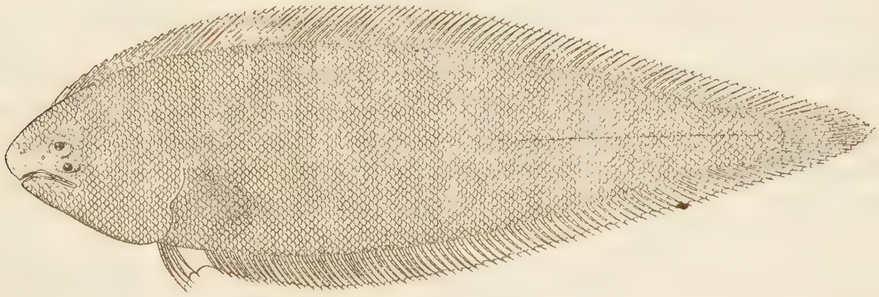

FIGURE 97.—*Symphurus plagiusa.* From a specimen 35 millimeters long

Young fish ranging from about 10 to 75 millimeters in length are few in our collection, very probably because of the method of collecting. Fish of this size are too big to be caught readily in 1-meter townets, yet too small to be held by the ordinary collecting trawl. A method of collecting fish of this size was not developed until toward the close of the investigation. The fish of these larger sizes contained in the collection, with a single exception, were taken within the harbor. It must not be concluded, however, that these young are more numerous in the harbor than at sea, as much less collecting with the recently devised apparatus was done at sea than within the harbor. The data do show, however, that the larger sizes (10 to 75 millimeters) are more common within the harbor and adjacent estuaries than the smaller ones.

The adult tonguefish, of course, is strictly a bottom-dwelling form. It is evident from the townet collections at hand that the young, too, live almost entirely on or near the bottom, for in an approximately equal number of drags made with two 1-meter townets, hauled simultaneously, one at the surface and the other one on the bottom, the fry were taken in 56 bottom collections and in only 3 surface ones. It seems evident from the results of collecting that the fry, if hatched from floating eggs (which is probable, as the other species of sole occurring locally, as well as one or more European species, are known to produce pelagic eggs), resort to the bottom at a very early age, as the great majority of the numerous specimens taken there are less than 7 millimeters long.

It may be concluded from the foregoing discussion, therefore, that the small fry locally occur almost entirely out at sea, where spawning no doubt takes place, and that the larvæ, like the adults, dwell almost exclusively on the bottom.

GROWTH

Insufficient specimens were taken to show the rate of growth, as individuals from about 10 to 75 millimeters in length are sparingly represented in the collections. We have several specimens, however, which evidently belong to the O class, taken in January, February, and March, when about 6 to 9 months old, ranging from 34 to 68 millimeters in length. It is believed that these specimens probably are representatives of the larger fish of the O class. If that be true, the rate of growth is not very rapid.

MONACANTHUS HISPIDUS (Linnæus). Foolfish

The foolfish is known from Nova Scotia to Brazil, and it is recorded also from the Canaries and Madeira in the eastern Atlantic. It is rather rare on the American coast north of Cape Cod and common southward. It is common at Beaufort during the summer, but certainly not abundant. During the winter it has not been seen. It is principally pelagic in its habits, living chiefly among plant growth along the shores and among floating plants and débris at sea.

Color simulation is highly developed, for the fish are bright green when found among vegetation of that color, or brownish if that happens to be the color of the plants among which the fish are taken, and so forth. The fish probably has need of the protection it derives from color simulation, as it is a sluggish fish and a poor swimmer. When caught in a net it makes no effort to escape, and not infrequently it even fails to swim away for some time after the net is removed. This seems so foolish to the fishermen that they have named this species, as well as its relatives which behave similarly, foolfish.

This foolfish is recognized by its short, deep body; in the adult the depth at the vertical from the vent generally being contained less than two times in the length of the body. It has a rough, spiny skin; a single high dorsal spine with barbs; and a rough ventral spine, beyond which a skinny, ventral flap does not extend, as in a related species. The foolfish is of no direct economic importance, as it is not eaten and its value indirectly, as food for commercial species, probably is slight. The literature contains very little information concerning the life history of this fish.

SPAWNING

The eggs of the foolfish have not been taken, or if so, they have not been recognized. Neither have fish with large roe been observed. In fact, few individuals exceeding a length of about 5 to 6 inches have been caught, although this fish is said to reach a length of 10 inches. The rather small individuals, commonly taken locally, probably are sexually immature. All that has been learned during the present investigation about spawning in this species, has been derived from the collection and the study of the young. It has been possible, however, in this way to obtain fairly accurate data relative to the place, time, and duration of spawning.

Very small young, 4 millimeters and under in length, were taken in townet collections from May to September and a few scattering ones, slightly larger in size, were taken in October, November, and as late as December 6 (1927). The fry were common from June to September, and the largest number was taken during July. The records of these collections, therefore, indicate that spawning may take place from May to about November, that the chief spawning season extends from June to September, and that it probably is at its height in July.

The distribution of the young, as shown on p. 486, indicates that in the vicinity of Beaufort spawning takes place entirely at sea. This would be expected because extensive collecting within the harbor and adjacent inside waters has yielded very few large foolfish; that is, fish over 5 or 6 inches in length, among which no individuals with developing roe have been observed. It is probable, therefore, that the mature fish live almost entirely at sea where they carry out the reproductive processes.

The extremely small size of the most recently hatched fry taken, which are only about 1.7 millimeters long, suggests that the foolfish produces a very small egg. Since the smallest fry, that is larvæ 4 millimeters and under in length, were nearly all taken in bottom hauls, although the larger ones were collected almost exclusively at the surface, suggests that the eggs may be demersal.

DEVELOPMENT OF YOUNG

The foolfish acquires adult characters and is readily recognizable as a foolfish at an extremely early age. This interesting fact is shown by the descriptions and drawings which follow.

Specimens 1.7 millimeters long.—Two specimens of about this size are at hand, only one of which is in good enough condition for an accurate description and illustration. The fry at this size have a robust body and a long, slender, pointed tail. The head is blunt anteriorly and extends only slightly beyond the large eye. The mouth is small and terminal. Fin folds extend around the entire caudal portion of of the body and are present for the pectorals and for *two* ventral fins. The last-mentioned fins fail to develop and are represented in larger fish by a single spine, attached to the pelvic bones. A spine, about equal in length to the diameter of the eye, already is present over the head, as in the adult, and at once identifies the larva as a foolfish. The spine is very slender at this age and without barbs or serrations. Dark pigment is present on the head, extending along the upper surface to the base of the dorsal spine. Similar dark pigment is present on the ventral fin folds and extends from thence along the upper margin of the abdomen to the vent and then as a row of somewhat larger dots along the ventral edge to the tip of the tail. (Fig. 98.)

The presence of the dorsal spine in combination with the deep body aid identification at this and all other ages.

Specimens 2 millimeters long.—The principal change in the structure, since a length of 1.7 millimeters was attained, is in the loss or union of the ventral fin membranes, for the two tufts of membrane present at the smaller size have disappeared and now a single flexible membranous fin is situated on the median line of the abdomen. It is not evident from the specimens at hand whether the pair of membranous tufts, resembling ventral fins, present in the very young are lost, or whether they become united to form the single membranous fin now present on the median line of the abdomen. This membranous appendage on the abdomen will soon develop into a strong spine. (Fig. 99.)

Specimens 3 millimeters long.—The body has become considerably deeper, especially in the anterior portion of the caudal region. Posteriorly the tail remains slender and pointed. The snout now projects rather prominently in advance of the eye and is becoming slightly conical, while the mouth is small and terminal, as in the adult. The dorsal spine is high and prominent, being equal to about two-thirds the depth of the body, and from its anterior and posterior margins project a few spiny barbs, variable in size. The ventral spine has become strong and rigid. The soft dorsal, caudal, and anal are becoming slightly developed with traces of rays, and small prickles are beginning to appear on the body covering. Dark pigment is present on the head and generally extends on the back. The ventral periphera, including the ventral spine, usually is slightly pigmented with black. Similar pigmentation occurs on the side above and behind the abdomen. (Fig. 100.)

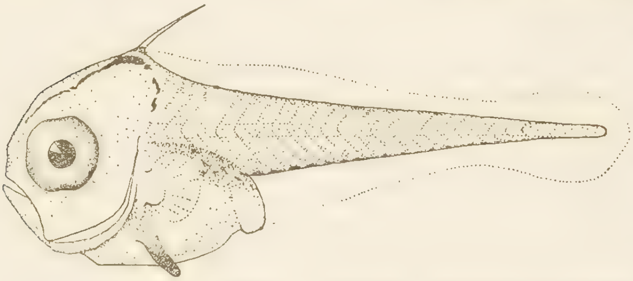

FIGURE 98.—*Monacanthus hispidus.* Drawn from a specimen 1.7 millimeters long

Specimens 5 millimeters long.—The body is shaped very much as in the adult. The tail now is moderately deep and it supports a well-developed, rounded caudal fin. The soft dorsal and anal, too, are fairly well developed. The barbs on the dorsal spine have increased in number and size, and the skin is now quite generally beset with prickles. Pigmentation in preserved specimens consists principally of dark dots scattered over the body.

Specimens 8 millimeters long.—Specimens 8 millimeters long are very similar to the adults in shape. The snout, however, remains much shorter and blunter. The dorsal spine still has large barbs on both the anterior and posterior margins; the ventral spine is very prickly and largely free, the membranous flap which later ties it to the abdomen being mostly undeveloped. The other fins are all well developed and shaped as in the adult. Pigmentation consists principally of brownish spots with dark centers, present everywhere on the body, exclusive of an area behind the eye and around the gill opening. (Fig. 101.)

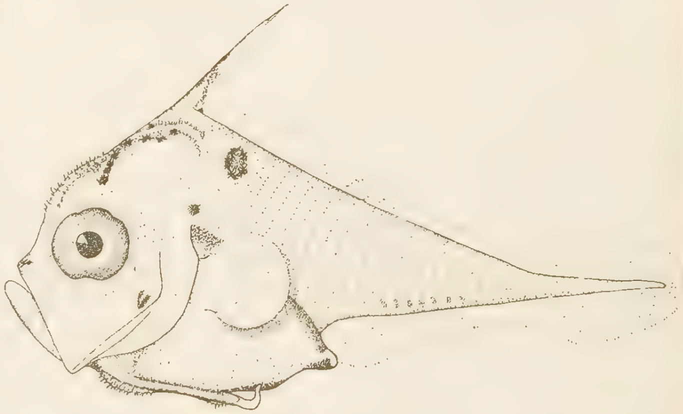

FIGURE 99.—*Monacanthus hispidus.* Drawn from a specimen 2 millimeters long

Specimens 15 millimeters long.—In shape and form the body is now identical with the adult, except that the snout remains too blunt and does not project as prominently as in grown fish. The barbs on the dorsal spine, especially those on the forward margin, have become proportionately much smaller since a length of 8 millimeters was attained; the ventral spine is prickly and is now attached to the abdomen by a membranous flap which is much more fully developed than in 8-millimeter specimens. Brownish spots with dark centers are present everywhere on the head and body. When seen with the unaided eye the body shows indications of dark marblings. The fins are almost colorless, as in the adult. Fish 15 millimeters long have acquired so many of the adult characters and are so similar to the fully grown fish that they are readily recognized by anyone familiar with the adult.

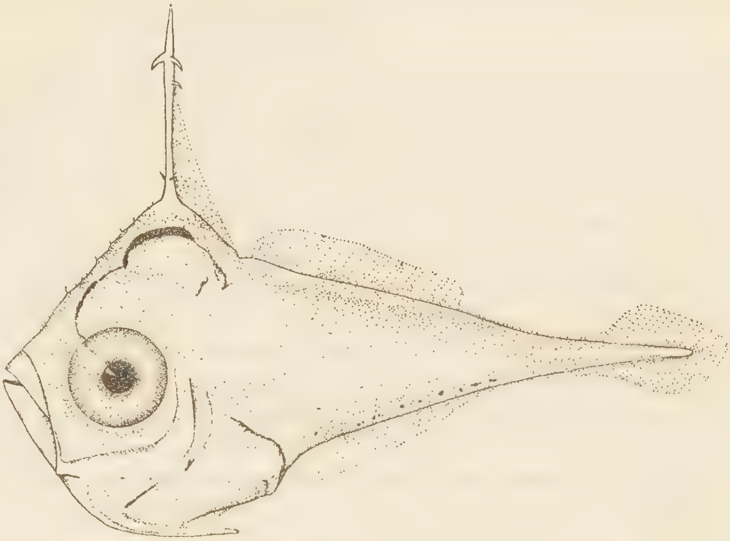

FIGURE 100.—*Monacanthus hispidus.* Drawn from a specimen 2.8 millimeters long

As the fish increases in length the snout continues to become more pointed and the dorsal profile over the snout gets more strongly concave. This lengthening of the snout continues even after the fish has reached a length of 75 millimeters. The barbs on the anterior margin of the dorsal spine gradually become smaller as the fish grows and generally are quite small or have disappeared when a length of 40 to 50 millimeters is reached. The ventral flap, situated between the ventral spine and the abdomen, varies somewhat in size among individuals of the same length, but generally increases in size with age, failing to reach the tip of the spine until a length, of

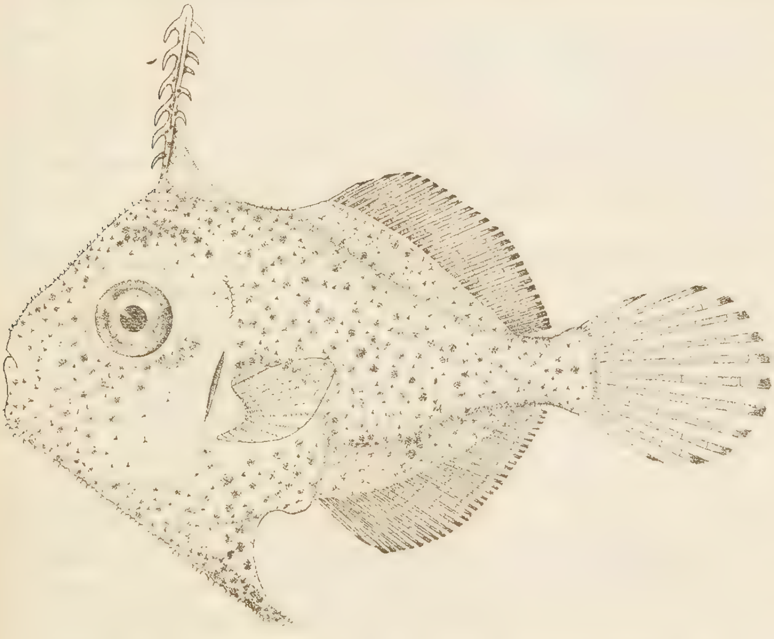

FIGURE 101.—*Monacanthus hispidus.* Drawn from a specimen 8 millimeters long

at least 75 millimeters is attained. The margin of this flap rarely extends slightly but never prominently beyond the tip of the ventral spine.

DISTRIBUTION OF YOUNG

The fry first appeared in the tow in May when only a few were taken and three young—5, 7, and 10 millimeters long—were collected as late as December 6 (1927). The last-mentioned specimens certainly may be considered stragglers, for they are the only foolfish of any age or size taken in December. Young foolfish were common in June, July, August, and September. They were most numerous, however, in July. These data are interpreted to indicate, then, that spawning may occur from May to about November, that the principal spawning season extends from June to September and that it probably is at its height during July. Neither the young nor the adults have been found in the local waters during the winter.

Small fry were not found in the inside waters. Only three specimens, all over 7 millimeters in length, were taken in townets within Beaufort Harbor and adjacent waters, all the others (over 300 specimens) having been secured outside. It is quite certain, therefore, that nearly all the young, locally, are hatched at sea.

The young were never taken in large numbers in any one haul. They were caught frequently, however, and generally only one or a few at a time. This seems to show that the young, like the adults, are solitary.

The young, exclusive of the very smallest ones, were taken at the surface much more frequently than on the bottom. For example, in an approximately equal number of hauls made with two 1-meter townets, hauled simultaneously, one at the surface and the other at the bottom, specimens of foolfish were taken in 80 surface towings and in only 12 bottom ones. Since the bottom net remained open as it was hauled in, it is quite possible that some of the specimens contained in this net were not caught on the bottom. It is interesting and worthy of note, however, that of the smallest larvæ secured—that is, fry of 3 millimeters and less in length, of which about 15 specimens are at hand—only 1 individual was taken in a surface haul, whereas only 9 larger ones were caught in bottom hauls. The results of this collecting appear to indicate that the recently hatched young occupy the bottom but come to the surface at a very early age.

Foolfish are rather infrequently taken locally in otter trawls, a type of net that fishes the bottom, and generally is hauled in water at least several feet deep. Individuals ranging from 25 millimeters upward are common in shallow grassy areas in the harbor during the summer, and they are also seen at sea swimming about or among floating plants. It is evident from the foregoing facts that the foolfish acquires its surface-dwelling habit at a very early age. It appears to retain this habit throughout life.

GROWTH

Measurements for the determination of the rate of growth have not been made and little information on this subject has been secured. Fish ranging from about 15 to 60 millimeters in length are common in collections made with seines in Beaufort Harbor during September. It is believed that the larger individuals, namely, those ranging from about 50 to 60 millimeters (2 to 2½ inches or so) in length are representatives of the earliest and largest young of the season. Upon the approach of cool weather in the autumn the fish withdraw from the shallow shore waters and comparatively few appear to return the next summer. Therefore, nothing has been learned about their growth after the first summer, nor has the age at which maturity is reached been determined.

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OXYGEN CONSUMPTION OF NORMAL AND GREEN OYSTERS[1]

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INTRODUCTION

The knowledge of the oxygen requirements of any bottom organism is essential in understanding the factors that control its distribution, growth, and adaptability to various local conditions. The purpose of the present investigation is to determine the rate of oxygen consumption of normal and green oysters and to evaluate some of the factors that govern the respiration of the lamellibranch mollusks.

The respiratory exchange of the oyster has been studied by Mitchell (1914), who found that at temperatures between 19° and 28° C. oysters of medium sizes used from 0.7 to 3.5 milligrams of oxygen per hour per 100 grams of entire weight (from 0.35 to 1.29 milligrams per hour per 1 gram of dried weight), and that they showed considerable resistance to lack of oxygen. He noticed also that the oxygen consumption was exceedingly variable, depending on a variety of conditions which, he thought, affected the opening and closing of the shell. No attempts were made, however, to eliminate or control these variables.

Nozawa (1929) in a study of normal and abnormal respiration of *Ostrea circumpicta* arrived at the conclusions that "the rate of the oxygen consumption is independent of the oxygen tension till its pressure is reduced to 0.1 per cent or below"; and that under abnormal conditions (pulling of the adductor muscle by a 5-kilogram weight attached to one side of a horizontally fixed shell) the gaseous metabolism of the oyster is accelerated.

There are several possible sources of error that may have an effect on the results obtained by Mitchell and Nozawa. The natural sea water used in their experiments may have contained organic matter that either consumed or liberated oxygen. In Nozawa's experiments the water in the experimental jars was not stirred and its oxygen content was probably not uniform. In Mitchell's experiments part of the oxygen was either directly absorbed by the substance of the shells or used up by

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[1] Submitted for publication May 12, 1930.

various organisms growing on them. In neither experiment was the effect of muscular activity eliminated.

In the present investigation attempt was made to eliminate or control all these variables and to carry out experiments under standard conditions. The experiments were carried out at the United States Bureau of Fisheries laboratory at Woods Hole, Mass. Normal oysters used in the experiments were received from Onset Bay, Mass. Green oysters were obtained from the commercial beds near New Haven Harbor in Long Island Sound. All the oysters before being used in the experiments were kept for at least two weeks in floats anchored in Woods Hole Harbor.

METHOD

The method of study of the oxygen consumption of nonambulatory organisms like the oyster is very simple. The oxygen content of the water is determined under standard conditions before the animal is put in and at given intervals thereafter; the difference, representing the amount of oxygen consumed, is calculated per unit of time and per unit of weight. In practice, however, there are a number of interfering factors (organic matter in the water, organisms grown on shells, muscular activity, etc.) that must be controlled.

Preliminary tests have shown that the sea water from the laboratory supply used in the experiment consumed appreciable quantities of oxygen. After it was passed through a ½-inch asbestos filter its oxygen content, under the conditions of the experiments, remained constant over a period of 9 hours. (Table 1.)

TABLE 1.—*Control experiment with filtered sea water. Closed chamber method*

Time, hours	Oxygen, c. c. per liter	Time, hours	Oxygen, c. c. per liter
0	4.56	5	4.59
1	4.62	6	4.58
2	4.58	7	4.62
3	4.60	8	4.57
4	4.65	9	4.60

The shells of the oysters were thoroughly scrubbed with a wire brush and then covered with paraffin. This treatment covered any remaining organisms and prevented the absorption of dissolved gases by the porous substance of the shell. A control experiment (Table 2) shows that during the period of 5 hours the oxygen content of the water, in which the shells treated in this way were kept, remained nearly constant.

TABLE 2.—*Control experiment with treated shells. Closed chamber method*

Time, hours	O_2 content, c. c. per liter	Time, hours	O_2 content, c. c. per liter
0	4.30	3	4.30
1	4.36	4	4.28
2	4.34	5	4.28

The control of the muscular activity presented a more difficult problem, which we attempted to meet in two different ways. At first the shells of the oysters were gently forced apart, great care being taken not to injure the mantle nor tear the adductor muscle, and small glass rods were inserted to hold the shells open. It was found, however, that frequently the glass rods were expelled. This indicated that the presence of a foreign body stimulated the contractions of the adductor muscle which in turn affected the amount of oxygen consumed. To obviate this difficulty another method was devised, whereby determinations were made on single oysters, mounted as described below, so that the opening and closing of the shell was recorded on a kymograph.

Two methods were used for the determination of oxygen consumption. In the first method, which in the following discussion is referred to as a closed chamber method, six oysters, the shells of which were kept apart by glass rods, were placed in apparatus similar to that used by Bruce (1926). (Fig. 1.) It consisted of a 14-inch diameter heavy glass desiccator with ground glass flanges held together with clamps and a rubber stopper on the top of the dome-shaped lid. Three glass tubes were arranged in the stopper; one, extending to 1 inch above the bottom, formed a syphon outflow; the second one ended just below the stopper and served for replenishing the water when a sample was being taken; through the third one, filled with paraffin oil, passed the stem of the stirrer. By simultaneously regulating the outflow and the inflow of the water, a sample was withdrawn and the water in the chamber replenished from a reservoir containing filtered sea water of a known oxygen content. The chamber was kept in a constant temperature bath.

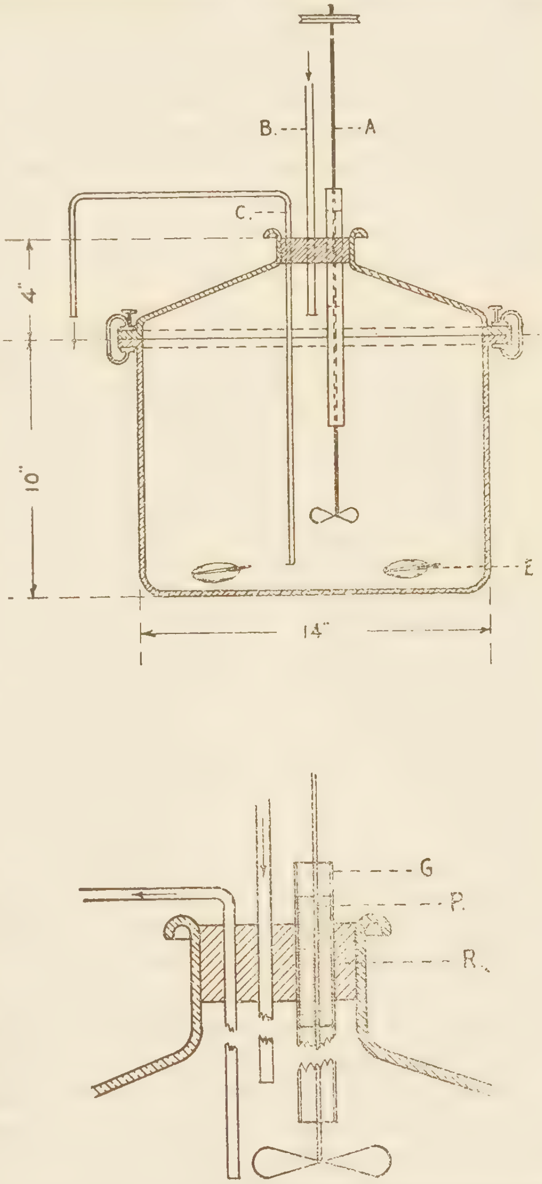

FIGURE 1.—Closed chamber for the determination of oxygen consumption. A, Glass stirrer; B, inlet; C, outlet; D, ground glass flanges on cover and base held together with clamps; E. oysters held open by means of small rods inserted between the valves; G, glass tubing in which stirrer rotates, sealed with paraffin oil; P, paraffin oil; R, rubber stopper

In the second method, which in the following discussion is referred to as open chamber method, the determinations of oxygen consumption were made on single oysters, the valves of which were connected to a recording lever of the kymograph. An oyster was placed in a 2-liter open jar filled with sea water. To prevent the exchange of gases between the air and the water the latter was covered with a 3-centimeter layer of heavy paraffin oil. It has been demonstrated by the work of Gaarder (1918) and Nozawa (1929) that the oil layer of this thickness intercepts completely the interchange of gases between the water and the air and that, after the equilibrium between the oxygen tension in the water and in the oil has been established the oxygen tension in the water covered with oil remains practically constant. The set up of the apparatus is shown in Figure 2. The chamber *A* filled with sea water was placed in a constant temperature water bath, *B*; the water in the chamber was stirred with an electric stirrer; two glass tubes served for taking a sample of water, *O*, and replenishing the supply of it, *I*, from bottle *R*, which contained filtered sea water.

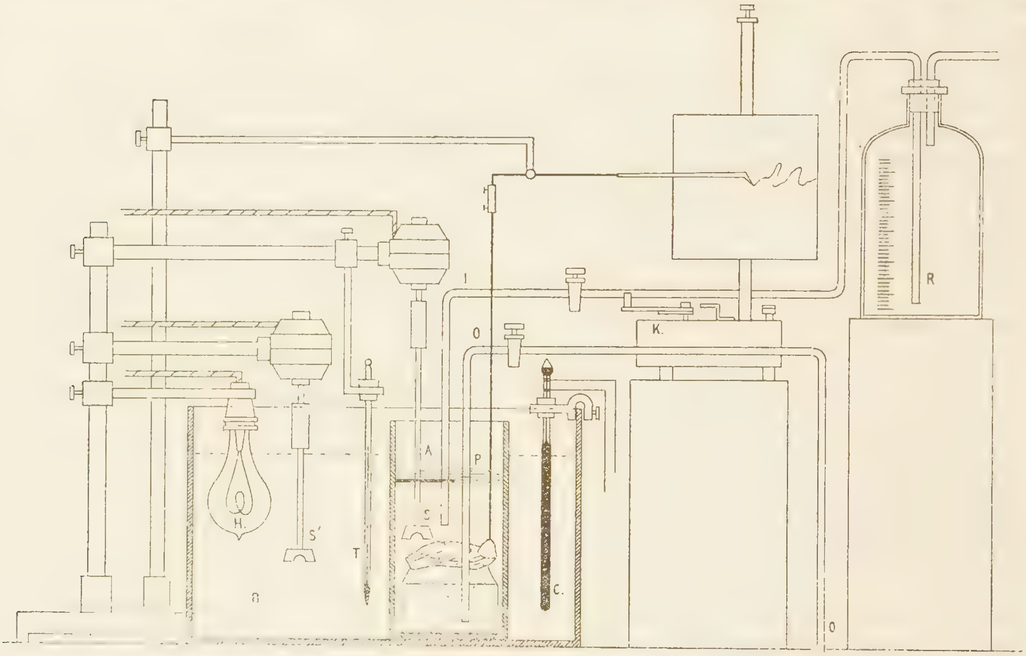

FIGURE 2.—Set up of the apparatus for the determination of oxygen consumption. Open chamber method. A, Glass jar (chamber) filled with water to the level indicated by the heavy line appearing just below oil layer (shaded ara); B, water bath; H, heater; C, metastatic temperature controller; I, glass tubing through which water is added; O, glass tubing for taking a sample; S and S′, electric stirrers; P, layer of paraffin oil; K, kymograph; R, bottle with filtered sea water of known oxygen content; T, thermometer. Relays to operate the temperature controller, dry cells, and rheostats for electric stirrers are not shown

Temperature of the bath was controlled by means of electric heater (*H*), stirrer (*S′*), and metastatic mercury temperature controller (*C*) set at 24.5° C.

At the end of the experiment the oyster was removed, the shells pried apart, and the liquor allowed to drain out for exactly 30 minutes. Then the meat was scraped out into a tarred crucible, weighed, and dried to a constant weight, first at 60° C., then at 100° C. In some instances this material was used for copper determination.

On several occasions when the oyster placed in the open chamber failed to open, opportunity presented itself to make control experiments. Determinations made at 1-hour intervals (Table 3) show that under these conditions neither the environment nor the oyster consume any oxygen. Thus, all oxygen consumed when the oyster is open may be justly attributed to the respiratory exchange of the organism.

TABLE 3.—*Control experiment showing that no oxygen is consumed when the oyster remains closed*

Time, hours	Oxygen, c. c. per liter	Remarks
0	4.37	Oyster closed.
1	4.30	Do.
2	4.30	Do.
3	4.34	Do.
4	4.00	Oyster open.

All oxygen determinations were done by the well known Winkler method, modified for the presence of organic matter. The latter modification was found necessary because considerable amounts of feces were present when the experiment had been run for more than 1 hour. All figures of oxygen content were corrected to 0° C. and 760 millimeter Hg.

All the experiments were carried on from July to September, inclusive, under the following conditions: Temperature of the water varied from 24.5° to 24.6° C.; salinity of the water from 30.0 to 31.0 per mille; pH at the beginning of the experiment from 7.9 to 8.3; oxygen tension at the beginning of the experiment varied from 3.495 to 4.66 cubic centimeters; oysters varied in size from 6.8 to 10.00 centimeters long and 4.4 to 7.8 centimeters wide; their dry weight varied from 1.019 to 2.080 grams.

The procedure of the experiments was as follows: The oyster was removed from the harbor in the late afternoon of the day preceding that on which it was to be used, was scrubbed, weighed, mounted on a brick, and both the oyster and brick were covered with a heavy coating of paraffin. The oyster was allowed to stand in the air overnight (by this treatment the oysters opened more quickly the next morning than when allowed to remain in water all night). In the morning the chamber was filled with filtered sea water to the 2-liter mark, the surface of the water covered with a heavy layer of paraffin oil, and the chamber allowed to come to constant temperature in the thermostat. Then the oyster was put in and adjusted to the kymograph and the stirrer connected. As soon as the oyster opened, a sample of water was removed for analysis and the time recorded.

In a few of the open-chamber experiments, where only a few readings were made, no fresh sea water was added to the chamber. In most of them, however, an amount of water approximately equal to that removed was added from a small reservoir, which was kept at constant temperature by the thermostat. Knowing the capacity of the chamber, the O_2-tension at the beginning, and at the end of the experiment, the number of cubic centimeters of oxygen used by the oysters per time interval was calculated.

OXYGEN CONSUMPTION OF NORMAL OYSTERS

The results of the determinations of the oxygen consumption of the normal oysters are shown in Table 4. One can see from the examination of this table that under the conditions of the experiment the average oxygen consumption varied from 6.45 to 15.04 milligrams per hour per 10 grams of dry weight. There were considerable fluctuations in the rate of oxygen consumption during the period of a single experiment which are difficult to interpret. In the experiments Nos. 8–13 the determinations were made on six oysters kept together in a closed chamber. On several occasions (experiments 8 and 11) there was a sudden increase in the rate of oxygen consumption, which may be attributed to the increase in muscular activity in the attempts made by the oysters to get rid of the glass rods which were introduced between their valves.

TABLE 4.—*Oxygen consumption of normal oysters*

Experiment	Date	Oyster	Time	pH	O₂ tension, c. c. per liter, 0 ° C 760 mm.	O₂ consumption, c. c. per hour per 10 grams dry weight		Remarks
						Single determination	Average	
8	July 26	28–33 incl	2.30		4.66		15.04	Closed chamber method.
			2.45		4.60			
			3.00		4.22	13.92		
			3.15		4.04	14.32		
			3.30		3.75	14.20		
			3.45		3.40	17.70		
9	July 29	34–39 incl	11.10	8.30	4.33		10.29	Do.
			11.35	8.20	3.91	10.65		
			12.10	8.11	3.44	10.20		
			12.40	8.02	3.31	10.50		
			1.10	7.98	2.92	9.81		
10	Aug. 1	40–45 incl	12.20	7.9	3.98		6.45	Do.
			12.50		3.08	6.28		
			1.20	7.8	2.72	6.28		
			1.50	7.7	2.24	5.93		
			2.20	7.6	1.94	6.84		
			2.50	7.5	1.69	5.45		
			3.20	7.5	1.43	7.68		
11	Aug. 3	46–51 incl	10.45	7.9	3.60		8.70	Do.
			11.15	7.8	3.06	7.96		
			11.45		2.46	10.50		
			12.15	7.6	2.11	8.66		
12	Aug. 6	52–57 incl	10.45		4.76		9.16	Do.
			11.00		4.49	7.86		
			11.30		4.02	9.20		
			12.00		3.62	8.95		
			12.30		3.05	9.04		
			1.00		2.72	10.01		
			2.00		2.07	9.81		
13	Aug. 9	58–63 incl	9.50		3.495		10.99	Do.
			10.20		2.865	14.50		
			11.20		2.06	10.52		
			11.50		1.713	9.60		
			12.50		1.37	9.35		
74	Aug. 17	74	11.00		4.24		8.97	Open chamber method.
			11.30		3.93	9.80		
			12.00		3.53	11.46		
			12.30		3.24	7.65		
75	Sept. 4	75	9.15	8.0	4.60		9.86	Do.
			9.45	8.0	4.26	10.49		
			10.15	7.9	3.89	9.94		
			10.45	7.7	3.74	8.15		
76	Sept. 12	76	1.35		4.07		7.73	Do.
			2.05		3.87	5.71		
			2.35			8.75		
			3.05		3.45	8.75		
77	Aug. 31	77	11.30	8.0			9.78	Do.
			12.00	7.9		10.08		
			12.30	7.9		9.72		
			1.00	7.9		9.56		
81	Sept. 12	81	9.30				10.78	Do.
			10.00			11.58		
			10.30			10.80		
			11.00			9.97		

In experiments 74, 75, and 81, determinations were made on single oysters the shells of which were connected to a kymograph. An analysis of the kymograph tracings disclosed the fact that there existed a considerable difference in the muscular activity of these oysters. For instance oyster No. 74 opened almost immediately and remained wide open with scarcely any contractions of the muscle. (Fig. 3 C.) Oyster 81 remained tightly closed for a little over 1 hour, then when it did open, the muscle went through a series of vigorous contractions (fig. 3 A) which lasted as long as the experiment was continued. Oyster 75 (fig. 3 B) in respect to the muscular activity occupied an intermediate position between the two others. As one can see from Table 4 the highest oxygen consumption was recorded in oyster 81, the muscular contractions of which were the most active.

An analysis of all the data when kymograph tracings were obtained was made. Kymograph records were grouped into three arbitrary classes (table 5) according to the number of contractions per hour. Class A comprised oysters which displayed vigorous contractions at the minimum rate of 30 per hour. Oysters that made 5 or less contractions per hour were placed in class C while those intermediate between the extremes, with more than 5 and less than 30 contractions per hour formed class B. By examining Table 5 one can see that the average consumption of oxygen was highest in class A and lowest in class C.

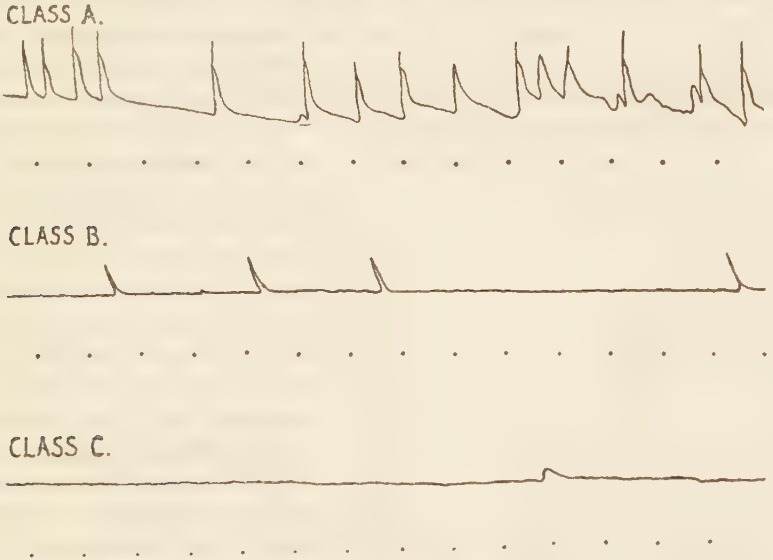

FIGURE 3.—Photograph of three kymograph tracings of shell movements used in the experiments. One-minute intervals indicated by dots. Class A, oyster No. 81; class B, oyster No. 75; class C, oyster No. 74

TABLE 5.—*Relation between the muscular activity and the oxygen consumption*

Class:	O_2 consumption, c. c. per hour per 10 g. dry weight
A (more than 30 contractions per hour)	10. 52
B (more than 5, less than 30 contractions per hour)	9. 80
C (5 or less contractions per hour)	8. 42

The scale is obviously only an approximation and fails to explain the fluctuations observed within each class or during one experiment. It is quite probable that besides muscular activity other factors are responsible for the differences in the rate of oxygen consumption observed during this work. One of them is related to the seasonal changes in the metabolic activity of the oyster. It has been demonstrated by Bruce (1926) that in *Mytilus edulis* the seasonal changes in absolute oxygen requirements are intimately associated with concurrent changes in the chemical composition of the tissues. It is probable that as the time of spawning approaches, the metabolic activity of the oyster increases and falls off again after the eggs or sperm have been expelled. This problem, however, was not studied during the present investigation.

Another cause of fluctuation in the rate of oxygen consumption may be found in the variation in the ciliary activity of the gill epithelium and consequently in the variation in the rate of flow of water through the gills. In a previous work one of us (Galtsoff, 1928) has shown that there exists a wide range of variation in the rate of flow of water through the gills of oysters of approximately equal size. Unfortunately, no method was suggested whereby the rate of flow of water in the oyster kept in the metabolism chamber could be determined.

EFFECT OF OXYGEN TENSION ON OXYGEN CONSUMPTION

The results of studies made by several investigators of the effect of oxygen tension on the oxygen consumption of various invertebrates are contradictory. Apparently much more experimental material must be accumulated before better understanding of the relationship existing between these two factors is obtained. It has been recognized by Thunberg (1905) that oxygen consumption of air breathing forms like Limax, Lumbricus, and Tenebrio is dependent upon the oxygen tension of the surrounding medium. Henze (1910) extended this work on a number of marine invertebrates and has demonstrated that while in some of the lower forms (Actinia, Anemonia, Sipunculus) the oxygen consumption decreases with the decrease in its tension, in the higher forms with well developed circulatory system (Carcinus, Scyllarus, Aplysia, Eledone) the consumption of oxygen is independent of its tension over a considerable range. Lund (1921) experimenting with *Planaria agilis* found that the rate of oxygen consumption of that worm was constant up to about 36 hours, at which time the oxygen tension became equal to about one-fourth or one-sixth of the oxygen tension of air-saturated water at 20° C. Amberson, Mayerton, and Scott (1924) reported that oxygen consumption of Limulus, Callinectes, and Palaemonites is directly proportional to the oxygen tension in the sea water. The opposite conclusion was reached by Helff (1928) who found that crayfish exhibits respiratory independence from oxygen tension over a considerable range. He found also that the critical tension is different for the organisms of different sizes. In small animals averaging 4.3 grams, the critical tension occurs at 20 per cent of saturation; in those averaging 9.0 grams, the limit is 30 per cent; and for large animals averaging 17.1 grams, the limit is 40 per cent. Below these respective limits the oxygen consumption becomes erratic.

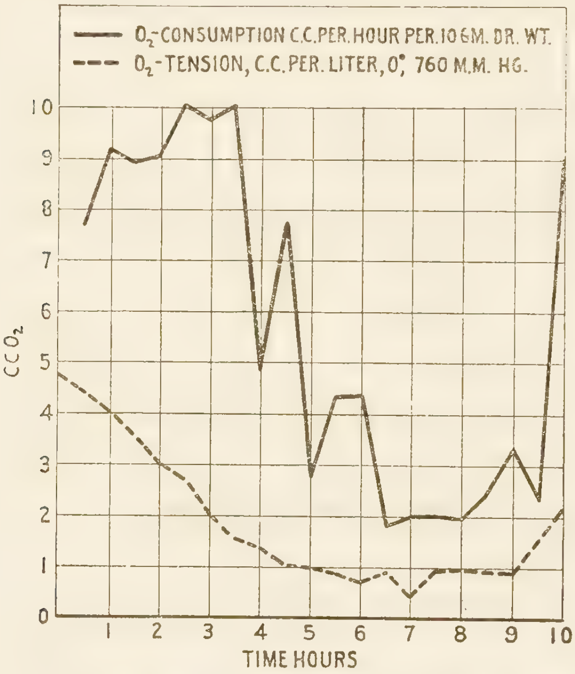

FIGURE 4.—The effect of oxygen tension on oxygen consumption

It is interesting that the respiratory exchange of unicellular forms (Paramaecium) and of the fertilized eggs (Arabacia) is virtually constant over a wide range of oxygen tenssion (Amberson, 1928).

Nozawa (1929) studied the effect of oxygen tension on respiration of the oyster and found that the rate of oxygen consumption of *Ostrea circumpicta* is independent of oxygen tension until the latter is reduced to 1 cubic centimeter per liter.

Several experiments to determine the effect of low oxygen tensions on the respiratory exchange of the American oyster were undertaken during the present investigation. The results of one of the experiments are as follows: At 10.30 a. m. six normal oysters were placed in a closed chamber and samples of water were removed at one-half hour intervals until 8.30 p. m. In spite of the fact that small amounts of fresh sea water were added each time the sample was removed, the concentration of oxygen in the water was reduced by the metabolism of the oysters themselves to a low level. The results of the experiment presented in Table 6 and Figure 4 indicate that the oxygen consumption was not affected until O_2 tension reached the level of approximately 1.50 cubic centimeter per liter. In order to determine whether the products of the metabolism that were allowed to accumulate in the water might conceivably influence the respiratory exchange, the oxygen in the chamber was replenished by bubbling air through the water for one-half hour (from 8.30 to 9 p. m.). In this way the oxygen was renewed and the pH rose from 7.5 to 7.9.

TABLE 6.—*Effect of oxygen tension on oxygen consumption and effect of products of metabolism on oxygen consumption*

Date	Oyster	Time	pH	O_2 tension, c. c. per liter 0° C., 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight
Aug. 6	52–57, inclusive	10.30	8.0	4.76	----------
		11.00	------	4.49	7.86
		11.30	------	4.02	9.20
		12.00	------	3.62	8.95
		12.30	------	3.05	9.04
		1.00	------	2.72	10.008
		2.00	------	2.07	9.81
		2.30	------	1.57	10.012
		3.00	------	1.08	7.73
		4.00	------	1.03	2.81
		4.30	------	0.90	4.36
		5.00	------	0.78	4.36
		5.30	------	0.915	1.895
		6.00	------	0.468	2.04
		6.30	------	0.953	2.04
Aug. 6	52–57, inclusive	7.00	------	1.005	1.918
		7.30	------	0.982	2.452
		8.00	7.5	0.920	3.362
		(1)	------	----------	----------
		9.00	7.9	2.44	----------
		9.30	------	2.28	2.315
		10.00	------	1.64	8.950
		(2)	------	----------	----------
Aug. 7	52–57, inclusive	12.20	8.0	4.80	----------
		1.20	------	4.26	6.298
		2.20	------	3.64	7.580
		3.20	------	2.775	6.33
		4.20	------	2.06	7.04
		5.20	------	2.281	5.61

[1] From 8.30 to 9.00 p. m., water in metabolism chamber was aerated.

[2] At 10 p. m. oysters were removed from the chamber, placed in running sea water until the next morning. Water in the chamber was then aerated for 2 hours, the same oysters put back in it, their oxygen consumption measured.

TABLE 7.—*Control on experiment in Table 6*

[Same six oysters, put in running sea water overnight. Next day oxygen consumption in fresh sea water determined]

Date	Oyster	Time	pH	O_2 tension, c. c. per liter 0° C., 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight
Aug. 8	52–57, inclusive	9.50	8.2	4.37	----------
		10.20	------	3.70	9.85
		10.50	------	3.28	6.75
		11.10	------	2.86	9.70
		11.45	------	2.51	7.27
Aug. 8	52–57, inclusive	12.15	------	2.05	7.16
		12.45	------	1.865	4.38
		1.15	------	1.345	9.70
		1.45	------	1.189	4.55

At 10 p. m. the oysters were removed from the chamber and put in fresh running sea water overnight. The next morning the water which had been used the previous day and which was full of the products of metabolism, was aerated until its oxygen tension was 4.80 cubic centimeters per liter and the pH was 8.0. The same oysters were put back in this water and their oxygen consumption again measured. It remained practically the same as it had been at the beginning of the experiment. (See Table 6.)

The next day an experiment was run on the same oysters using fresh sea water of high oxygen content and normal pH (8.2) to see if the oysters had suffered any from their exposure to water full of the products of their own metabolism. No effect whatever was noticed. (See Table 7.)

In another series of experiments the sea water was boiled under vacuo until the oxygen content had been reduced to less than 1.50 cubic centimeters per liter. The temperature during the process was not allowed to rise above 30° C. An experiment was performed using this water at pH 8.0. The results given in Table 8 indicate that at low oxygen content the rate of oxygen consumption gradually declined with the drop of oxygen tension.

TABLE 8.—*Effect of reduced oxygen tension on oxygen consumption*

[(Water under vacuo 48 hours at maximum temperature 30° C.) August 27, Oyster No. 75]

Time	pH	O_2 tension, c. c. per liter, 0° C., 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight	Time	pH	O_2 tension, c. c. per liter, 0° C., 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight
10.45	8.0	1.375	----------	3.15	7.6	0.396	1.610
11.15	7.9	.915	11.07	(1)	----------	----------	----------
12.15	7.8	.825	7.78	5.30	7.9	3.70	----------
1.15	7.7	.581	4.77	6.00	7.9	3.42	5.74
2.15	7.7	.499	1.438				

[1] Air bubbled through chamber for 2 hours.

The validity of the experiments in which the oxygen tension is decreased by the metabolism of the organism whose oxygen consumption is being measured, is open to criticism (Keys, 1930, Hall, 1929) on the grounds that the effect measured is not produced by a diminished oxygen tension alone but is due to the concurrent increase in carbon dioxide content and a corresponding decrease in the pH value of the water. In the light of the experiments of Wells (1913, 1918) and Shelford and Powers (1915), who demonstrated that fishes are very sensitive to very small changes in the pH and that their respiration is profoundly influenced by the hydrogen-ion concentration of the sea water (Powers, 1921, 1922), this criticism appears to be justified. It has been shown by the present investigation (Table 7) that the oxygen consumption of the oyster is not affected by the products of its own metabolism. The experiment fails, however, to check up the possible effect of the accumulation of the carbon dioxide which was driven out of the water when the latter was aerated. In order to distinguish completely between the effect of decreased oxygen tension and increase in CO_2 content, the following experiment was performed: Using the open chamber method, the rate of oxygen consumption under normal conditions (O_2 tension 4.0–4.5 cubic centimeters per liter; pH 7.9–8.0) was first determined. Then the CO_2 from a gas generator was bubbled through until the pH was reduced to 7.7. Again determinations were made and again the pH was lowered. This was continued until the pH value of 6.6 was obtained. Because the pH could not be lowered further by bubbling in carbon dioxide, 100 cubic centimeters of N/100 acetic acid were added. This brought the pH down to 6.0. It was difficult, however, to maintain this hydrogen-ion concentration for any length of time because the calcium carbonate of the shells acts as a buffer and brings it up to 6.4 very quickly. Table 9 embodies the results of this experiment. It indicates very clearly that oysters are not susceptible to changes in hydrogen-ion concentration such as can be brought about under experimental conditions by their own metabolism. There was a noticeable decrease in the rate of oxygen consumption from pH 6.6 downward.

Table 9.—*Effect of decrease in pH on oxygen consumption*

[Oyster No. 75]

Date	Time	pH	O_2 tension, c. c. per liter	O_2 consumption, c. c. per liter per 10 g. dry weight	Remarks	Date	Time	pH	O_2 tension, c. c. per liter	O_2 consumption, c. c. per liter per 10 g. dry weight	Remarks
Sept. 4	10. 30	8. 0	4. 520	----------		Sept. 6	12. 45	6. 2	3. 62	----------	CO_2 bubbled in.
	11. 00	8. 0	4. 448	11. 60			1. 15	6. 2	3. 482	4. 96	
	11. 30	7. 9	4. 000	10. 07			1. 45	6. 6	3. 250	2. 85	
Sept. 5	10. 20	7. 7	4. 21	----------	CO_2 bubbled in.	Sept. 6	2. 15	6. 0	2. 658	----------	100 c. c. N/100 acetic acid added.
	10. 50	7. 7	3. 74	8. 15			2. 45	6. 1	2. 550	2. 96	
	11. 20	7. 7	3. 24	9. 87			3. 15	6. 3	2. 470	1. 766	
Sept. 5	11. 25	7. 3	3. 60	----------	Do.	Sept. 6	3. 20	8. 0	4. 51	----------	Fresh sea water.
	11. 55	7. 3	3. 15	10. 16			3. 50	8. 0	4. 270	6. 40	
	12. 25	7. 5	2. 85	10. 84			4. 20	7. 9	4. 00	7. 95	
Sept. 6	11. 35	6. 6	----------	----------	Do.						
	12. 05	6. 6	3. 655	8. 15							
	12. 36	6. 6	3. 150	10. 84							

The experimental data presented in Table 6 and Figure 4 show that below the oxygen tension of 1.50 cubic centimeters per liter the oxygen consumption began to decrease following the further decrease in oxygen tension. Because of the small number of observations and on account of considerable individual fluctuations in the metabolic rate, it is impossible at present to determine accurately the critical oxygen tension below which the consumption of oxygen by the oyster is proportional to its pressure. It is quite possible that critical tension is also subject to certain individual fluctuation. The dependence of the oxygen consumption on oxygen tension can be demonstrated, however, by an analysis of all the data obtained with various oysters, the metabolic rate of which was measured at various oxygen tensions. Such an analysis is possible because in all the experiments the temperature was kept constant and because, as has just been demonstrated, the fluctuations in the pH values between 8.0 and 6.7 have no effect on the consumption of oxygen. An examination of Table 10 shows that in the lower half of it (oxygen tensions below 2.5 cubic centimeters per liter) there is a definite correlation between the two variables, which in the upper half of the table (range between 2.5 and 4.5 cubic centimeters per liter) appear to be independent of each other. This relationship can be expressed in mathematical terms. First a coefficient of correlation using all the data as given in Table 10 was calculated. Then similar coefficients were computed using the data of oxygen consumptions obtained at the oxygen tensions between 2.50 and 4.5 cubic centimeters and between 0.0 and 2.49 cubic centimeters per liter. The results are as follows:

Coefficient of correlation (all values)-- $r = +.498 \pm .048$
Coefficient of correlation (O_2 tension above 2.5 cubic centimeters)-------------- $r_1 = +.146 \pm .102$
Coefficient of correlation (O_2 tension below 2.5 cubic centimeters)-------------- $r_2 = +.646 \pm .046$

TABLE 10.—*Correlation table showing relation between oxygen consumed and oxygen tension*

Oxygen, c. c. per liter	Oxygen used, c. c. per hour per 10 g. dry weight															
	0–0.9	1–1.9	2–2.9	3–3.9	4–4.9	5–5.9	6–6.9	7–7.9	8–8.9	9–9.9	10–10.9	11–11.9	12–12.9	13–13.9	14–15	Total
4.50–4.25					1									1		2
4.24–4.00				1		1	1	1		2						6
3.99–3.75						1			1		1					3
3.74–3.50						1		1	2	1						5
3.49–3.25				1		1		2	1	1	1					7
3.24–3.00						1	1		1						1	4
2.99–2.75						6	1	1	2	1						11
2.74–2.50					2				1	1						4
2.49–2.25				1			1								1	3
2.24–2.00							1	1		1	2		1			6
1.99–1.75					1	2	1	1	1	1						7
1.74–1.50				1	1	1			1	1	1	1			2	9
1.49–1.25					1		2	1		2						6
1.24–1.00	1			3	1		1		2	1						9
0.99–0.75	1	1	2	1		3	1									9
0.74–0.50		2	2	2	2	1	2									11
0.49–0.25	5		1	2	1	2										11
0.24–0.00		1														1
Total	7	4	5	12	10	20	12	8	12	12	5	1	1	1	4	

The above expresses in mathematical terms what can roughly be seen from the correlation table; namely, that the oxygen consumption is independent of oxygen tension when the latter is above 2.5 cubic centimeters per liter, and that below that point the rate of oxygen consumption diminishes as the O_2 tension decreases.

It must be borne in mind that the statistical treatment of a series of observations permits the measurement of the relationship between the two variables but can not reveal the cause or causes of the phenomena observed. For the latter purpose further experimentation is necessary. It was thought that the dependence of oxygen consumption on oxygen tension may be due to the inhibition of the ciliary activity of the gill epithelium and to the consequent decrease in the rate of flow of water through the gills. Using the method developed by the senior author and described in previous publication (Galtsoff, 1928), the rate of flow of water through the gills was measured at various oxygen tensions. The results of two experiments are presented in Table 11. An oyster was first placed in the sea water which for three days was kept under vacuo at 37° C. Oxygen determinations and pH readings were made simultaneously with the measurements of the rate of flow. Then the water was aerated for 1 hour and readings were repeated. The results of the experiments show no significant differences in the rate of flow of water at the oxygen tensions of 0.69 and 5.45 cubic centimeters per liter.

TABLE 11.—*Rate of flow of water through the gills at normal and low oxygen tensions*[1]

Experiment and date	Time	Temperature ° C.	O_2, c. c. per liter	pH	Rate of flow, c. c. per hour			
					Average	Maximum	Minimum	Number of readings
A, Sept. 1	[2] 11.20	20.0	0.69	7.9	972	1,030	946	20
	1.27	19.3	5.45	7.8	900	1,011	810	20
B, Sept. 4	[2] 11.22	22.2	0.975	7.9	2,657	2,702	2,430	20
	12.55	22.2	4.52	7.7	2,683	2,702	2,430	29

[1] Size of the oysters: Experiment A, 8.4 by 7.6 cm., wet weight of meat 14.5 g.; experiment B, 9.7 by 7.8 cm., wet weight of meat 32.7 g.

[2] After these readings, air bubbled in.

Similar experiments were carried out to demonstrate the effect of the pH on the ciliary activity. The changes in the pH were obtained by bubbling the CO_2 through the water in which the oyster was kept. The results (Table 12) show that significant decrease in the rate of flow of water occurs when the pH is below 6.6. As has been shown before (Table 9), oxygen consumption at this pH also decreases.

These experiments demonstrate very clearly that the decrease in the rate of metabolism at low oxygen tension is not due to the failure of the gill epithelium to maintain sufficiently strong current. As the oxygen tension goes down, the amount of water passing through the oyster remains approximately the same. The rate of oxygen absorption remains at a constant level until a point is reached at which the amount of oxygen in the water is insufficient to supply the needs of the gill cells; that is, all the reduced material does not become oxidized. In normal sea water the oxygen content is far in excess of the oxygen requirements, which probably accounts for the wide range of oxygen tension to which the oyster is not sensitive.

TABLE 12.—*Effect of pH on the rate of flow of water through the gills* [1]

Experiment and date	Time	Temperature °C.	O_2, c. c. per liter	pH	Rate of flow, c. c. per hour			
					Average	Maximum	Minimum	Number of readings
C, Aug. 21, 1928	[2] 11. 38	22. 0	4. 59	8. 1	2, 527	2, 689	2, 112	20
	[2] 12. 20	21. 4	4. 65	7. 5	2, 961	3, 240	2, 696	20
	[2] 1. 16	21. 4	----------	7. 3	2, 670	3, 240	2, 313	20
	[2] 2. 18	21. 4	----------	6. 4	2, 074	2, 203	1, 672	20
	4. 00	21. 2	4. 60	6. 3	1, 095	1, 277	1, 011	20
D, Aug. 23, 1928	[3] 10. 35	21. 3	2. 62	8. 1	3, 078	3, 240	2, 864	20
	11. 57	21. 6	6. 11	8. 1	2, 573	3, 039	2, 112	30
	1. 30	21. 0	5. 65	8. 1	2, 670	2, 864	2, 313	20
	[4] 2. 10	21. 0	5. 50	8. 1	2, 307	2, 430	2, 028	20
	[2] 2. 30	21. 1	----------	6. 7	2, 29[illegible]	2, 430	2, 112	20
	[2] 3. 04	21. 3	----------	6. 5	2, 093	2, 210	1, 944	20
	4. 00	21. 6	4. 37	6. 1	1, 108	1, 218	972	20
E, Aug. 24, 1928	[2] 11. 10	27. 8	1. 58	8. 0	4, 802	5, 391	4, 413	20
	[2] 11. 27	27. 8	----------	6. 5	2, 825	3, 240	2, 430	20
	[2] 12. 05	26. 8	----------	6. 3	2, 346	2, 702	1, 944	20
	1. 40	26. 4	----------	6. 5	2, 929	3, 264	2, 702	20

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[1] Size of Oysters: Experiment C, 9.3 by 6.4 cm., wet weight of meat 13.56 g.; Experiment D, 8.1 by 6.4 cm., wet weight of meat 9.68 g.; Experiment E, 9.2 by 7.6 cm., wet weight of meat 21.6 g.

[2] After these readings, CO_2 bubbled in.

[3] After these readings, air bubbled in.

[4] After these readings, water was changed and CO_2 bubbled in.

INCREASED RATE OF METABOLISM

The oxygen consumption of any organism, of course is dependent on the kind of material that it is oxidizing. The normal diet of the oyster, comprising diatoms and other small plant and animal forms, is a "mixed" one containing protein, fat, and carbohydrate. It is also known (Young, 1928) that the oyster can utilize dissolved food material that is brought to it. It was thought, therefore, of interest to find out to what extent an abundance of food could be consumed. The oyster has no ability to select its food, so that anything that is in solution must necessarily pass through the animal; the question then is, what is the limit to which it can burn the material present?

To determine this the following experiment was performed: A series of control determinations was first made of the oxygen consumption of an oyster that was kept in the filtered sea water in an "open chamber" and the shell movement of which were recorded on a kymograph. After a base level of oxygen consumption had been determined, 1 cubic centimeter of a 5 per cent solution of glucose was added to the water, and the rate of oxygen consumption was measured over a period of several hours; then another cubic centimeter of 5 per cent glucose was added. Usually after the addition of 3 cubic centimeters the oyster closed up and remained so until the water had been changed.

It can be seen from Table 13 that the rate of oxygen consumption rose immediately after the introduction of the glucose, but it apparently reached its maximum very quickly, because subsequent increase in glucose was without effect until the concentration was sufficient to cause the oyster to close its shell.

TABLE 13.—*Effect of addition of glucose on oxygen consumption*

[September 6, Oyster No. 75]

Time	O_2 tension, c. c. per liter 0°, 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight	Time	O_2 tension, c. c. per liter 0°, 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight	Time	O_2 tension, c. c. per liter 0°, 760 mm.	O_2 consumption, c. c. per hour per 10 g. dry weight
11.00	4.65	----------	5.01	----------	----------	7.00 [2]	2.76	12.38
11.30	4.45	5.62	5.30	4.11	13.70	7.01	----------	----------
12.00	----------	8.84	6.01 [2]	3.96	14.45	7.30	2.42	13.87
12.30 [1]	3.78	8.84	6.00	----------	----------	8.00 [3]	1.98	14.12
5.00 [2]	4.62	----------	6.30	3.32	----------			

[1] Oyster closed, and experiment was discontinued for a few hours. Oyster opened at 5 p. m.
[2] 1 c. c. of 5 per cent glucose added.
[3] Oyster closed.

EXPERIMENTS WITH GREEN OYSTERS

The problem why oysters become green in certain localities has attracted the attention of biologists interested in a scientific study of this phenomenon and of those concerned with the oyster industry. Inasmuch as a good review of the extensive literature on the subject can be found in the papers of Herdman and Boyce (1899) and Ranson (1927), it suffices to mention here only a few essential points that have direct bearing on the problem. The present investigation refers to those green oysters the color of which is associated with the accumulation of copper in their bodies. It does not concern the so-called green-gilled oysters (from marennes) the coloration of which is due to the absorption of the pigment of a diatom, *Navicula ostearia*.

It has been demonstrated by Ryder (1882) that the green coloring matter of the American oyster is taken up by the amœboid cells which aggregate in cysts under the epithelium of the body and on the surface of the gills. Ryder suggested that the green pigment in the leucocytes may be phycocyanine. Later on it has been shown by Herdman and Boyce (1897, 1899) that comparatively large quantities of copper occur in the green leucocytes and that the intensity of the green color of the oyster is in proportion to the amount of copper present. They found that green American oysters relaid in the waters near Fleetwood, England, contained on the average 2.63 milligrams of copper per oyster, whereas normal oysters from the same source contained only 0.7 milligram of copper. Microchemical examination made by these authors proved that copper reaction coincided histologically with the presence of green leucocytes. The cause of green color was investigated by Colwell and Nelson [2] who arrived at the conclusion that copper is responsible for the bluish-green color of oysters from Narragansett Bay and certain sections of Long Island Sound. A different view was held by J. Nelson (1915) who believed that the green color is not due to copper.

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[2] Unpublished manuscript in files of U. S. Bureau of Fisheries.

The problem was complicated by the fact that the early investigators did not clearly distinguish between the types of green pigmentation and confused the blue-green pigmented oysters with the green-gilled ones. It is generally agreed at the present time that the former is associated with an increase in copper content and that the latter, which may have a normal copper content, is due to the accumulation of the pigment of the diatom *Navicula ostearia.*

Hunter and Harrison (1928) have shown that oysters taken from the vicinity of manufacturing centers may contain appreciable quantities of arsenic, zinc, and lead, besides copper. In some samples taken from New York Harbor and from Connecticut waters, the metallic contamination could be easily traced to the pollution of water by trade wastes. Yet in several instances oysters from areas located far from any known source of metallic contamination were found to contain considerable quantities of zinc and copper. The question of the source of copper in the sea and of the mechanism of its accumulation by the oyster has not yet been satisfactorily solved. Hunter and Harrison (loc. cit.) believe that oysters will absorb from the water almost any substance which it contains. The problem, however, requires further investigation.

A review of the literature reveals the fact that no systematic efforts were made to determine the chemical nature of the green pigment of oysters. Such an effort was made during the summer of 1927 by the senior author and Dr. Samuel Lepkofsky. First a series of analyses for copper was made on a large number of green oysters from Long Island Sound and of normal oysters from Wellfleet Harbor, Mass. The latter locality was selected because it was known that green oysters never occurred in Wellfleet Harbor. For microchemical reactions, sections of green and normal oysters preserved in absolute ethyl alcohol and embedded in paraffin were treated with potassium ferrocyanide and with haematoxylin. The results of these analyses confirmed fully the conclusions of Herdman and Boyce that the intensity in green color was in proportion to the copper content in the oyster and that histologically the copper is located in the green leucocytes.

The next step was to isolate the green substance and to attempt to determine its chemical composition. Unfortunately, because of the separation of Doctor Lepkofsky from the bureau, this work has not been finished. It is, however, desirable to give a brief account of the results so far obtained.

The green pigment generally associated with mollusks is a copper-protein complex, hemocyanin. It was thought that the green compound in oysters might be of a similar nature. The isolation of the green substance was attempted with the view of studying its chemical properties and using this information in an effort to remove the substance from the oyster or prevent its appearance. To obtain the pigment, oysters were ground in water with pure sand, which had been previously treated with strong HCl and carefully washed.

Green extracts obtained by this method were then saturated with $(NH_4)_2SO_4$ which caused all the proteins to be precipitated, but the pigment was not thrown out of solution. This indicated it was not a hemocyanin or a copper proteinate of any kind. Treatment with Na_2SO_4 at 37° C. did not precipitate the green color.

Finally, dialysis showed the pigment passed through collodion sacs which held back congo red. This indicated that the green compound was of a small molecular size.

Dialysis was then used as a method of preparing the green substance and concentrating it with the hope of obtaining some crystals when sufficiently concentrated. From three to four hundred green oysters were ground very fine through a meat grinder and extracted with water by pressing through several layers of cheesecloth. The extract was first dialyzed in collodion sacs impermeable to congo red, then concentrated in vacuo. A thick sirup was finally obtained, but no crystals were formed because of the large amount of impurities.

Some of the properties of this concentrated protein-free extract are: Heating to boiling destroys the color. Addition of alkali gives the blue-purple color of the biuret test. Heating of the alkaline solution causes a precipitate of cuprous oxide, indicating the presence of sugar or other reducing substance. H_2S decomposes the pigment readily with the formation of CuS. A steel spatula immersed in the green liquid soon becomes copperplated. This indicates that the compound exists in a highly dissociated state. One drop of HCl to about 5 cubic centimeters of extract causes a discharge of the green color. It apparently is not a simple copper salt as $CuCl_2$, Cu, Br, or $Cu(C_2H_3O_2)_2$, since addition of ammonia does not greatly deepen the color, as is the case with such copper salts. Boiling the extract discharges the color, thus necessitating vacuum distillation when concentrating.

An attempt was made to determine whether the compound existed as a copper ammonium complex. Aeration to remove ammonia before and after decomposition with H_2S failed to reveal evidence of a copper ammonium complex.

While the evidence cited indicated that the compound was not identical with or even remotely related to hemocyanin or other copper protein complex, it was nevertheless thought possible to exist in the oyster as a copper protein complex and possibly suffer decomposition on treatment with water used in the extraction. To settle this point, the following experiment was carried out. Normal white oysters were ground up and the oyster fluids obtained by pressing through a cloth. Green oyster fluids were similarly obtained and the one dialyzed against the other. Some of the green pigment diffused through the collodion sac tested previously for tightness with congo red, leaving no doubt that the green pigment exists in the oyster as a simple, readily diffusible compound.

The green pigment is quite readily soluble in methyl alcohol, less so in ethyl alcohol, and quite insoluble in butyl or amyl alcohol. It is insoluble in such fat solvents as chloroform, ether, acetone, or benzene. It is soluble in pyridine.

On standing about three or four months, the green color disappears and the extract turns to a reddish chocolate color. It was thought that it might represent a reduced form of the green pigment. Bubbling air or oxygen through the extract does not bring back the green color. Upon shaking with methyl alcohol, ethyl alcohol, or pyridine, the color returns in these solvents.

OXYGEN CONSUMPTION OF GREEN OYSTERS

The deposition of large quantities of copper in the oyster was regarded by Boyce and Herdman (1897) as a degenerative reaction which may be due "to a disturbed metabolism, whereby the normal copper of the hemocyanin, which is probably passing through the body in minute amounts, ceases to be removed and so becomes stored up in certain cells." It was thought that the determination of the metabolic rate of green and normal oysters would supply evidence in favor of or against this suggestion. Green oysters differing widely in depth of pigmentation were obtained from various sections of Long Island Sound. Inasmuch as previous work of Herdman and Boyce

(1899) and our observations during the summers of 1927 and 1928 have demonstrated that all intensely green oysters have high copper content, the latter was used as an index of the intensity of pigmentation.

The copper method used was that of R. Biazzo (1926), which was found to give excellent checks on very small amounts of copper, and was therefore suitable for determinations on single oysters. Because of slight variations in the method as we used it and also because the Italian journals are not always readily obtainable, the method is given below in detail:

Individual oysters were dried to constant weight in crucibles. The dried weight used was between 1 and 2 grams. The material was carefully scraped out into a large test tube and 5 cubic centimeters concentrated H_2SO_4 and 1 cubic centimeter of a saturated solution potassium chlorate added. After the mixture stopped foaming, it was gently heated with a microburner and boiled until all the organic matter had been oxidized. The process was usually hastened by the addition of 1 or 2 drops of hydrogen peroxide. Test tubes were covered with watch glasses to prevent any spattering during the combustion. After the solution had cleared, it was emptied into a 50-cubic-centimeter beaker and evaporated to dryness on the sand bath to render the silica insoluble. The residue was moistened with 5 cubic centimeters of 1N HCl followed by 5 cubic centimeters of water, warmed on the sand bath for one-half hour, filtered, and the precipitate washed in about 90 cubic centimeters of water. The filtrate is evaporated to a volume of 10 cubic centimeters, cooled, and enough 1N NaOH added to make the solution just alkaline to phenophthalein. Next 1 cubic centimeter of glacial acetic acid, 1 cubic centimeter of 10 per cent potassium thiocyanate solution, and 10 drops of pyridine were added. The solution was transferred to a 25-cubic-centimeter volumetric flask, 5 cubic centimeters of chloroform added, and the volume made up with water. After thorough shaking, the chloroform layer was allowed to settle, the aqueous layer removed, and the chloroform compared with a standard in the colorimeter.

Preparation of the standard: Dissolve 0.3926 gram of pure copper sulphate ($CuSO_4.5H_2O$) in water and dilute to 1 liter. One cubic centimeter of this solution contains 0.1 milligram copper. Take 1, 2, 3, and 5 cubic centimeters of this solution and treat with acetic acid, potassium thiocyanate, pyridine, and chloroform in exactly the same manner as the sample. Select the standard which has approximately the same intensity of color as the sample.

NOTE.—(1) Water distilled in glass must be used throughout, (2) a control must be run on all reagents used, (3) the copper compound formed has the formula $CuPy_2(CNS_2)$.

As a check on the method, 25 normal white oysters were dried to constant weight at 100° C., ground, and put through a 60-mesh sieve. This made a homogeneous powder, samples of which could be used for copper determinations. One-gram samples of this powder were analyzed according to the above method; 1-gram samples to which had been added 1 cubic centimeter of a standard copper solution containing 0.1 milligram of copper were also analyzed. The results are presented in Table 14.

TABLE 14.—*Control analysis of copper determinations*

Material	Cu, mg. in 1 g.	Average	Calculated	Material	Cu, mg. in 1 g.	Average	Calculated
Mixed sample of dried oysters	0.1138 0.1158 0.1142 0.1164	0.1151		Same plus 0.1 mg. Cu	0.2136 0.2120 0.2110 0.2116	0.2121	0.2151

NOTE.—Control on the reagents gave no color.

By examining Table 15, which contains all the data of oxygen consumption of oysters of known copper content, one can notice that the respiratory rate of the green oysters was slightly higher than that of the normal ones. It must be borne in mind, however, that high oxygen consumption was observed also in the normal oysters. (See Table 4, experiment 8.) Unfortunately, no copper determination of these oysters was made, but it is very doubtful if their copper content was high, because during the course of the investigation no normal oyster was found that had high copper content. While the relationship between the oxygen consumption and copper content can not be definitely established, the results of the present investigation indicate very clearly that the metabolic rate of the green oysters was at least equal to, and probably higher than, that of the normal oysters. The conclusion can be drawn that so far as the rate of metabolism is concerned, there is no indication of any disturbance due to the accumulation of copper.

Table 15.—*The relation of the copper content of oysters to the oxygen consumption*

Experiment	Date	Oyster	Dry weight	Cu. mg. per 100 g. dry weight	Cu. mg. per oyster	O_2 consumption, c. c. per hour per 10 g. dry weight
NORMAL OYSTER						
10	Aug. 1	40–45 incl	[1] 2.07	[2] 8.21 8.26	[2] 0.170 0.171	6.45
11	Aug. 3	46–51 incl	[1] 2.08	[2] 9.90 9.52	[2] 0.206 0.198	8.70
12	Aug. 6	52–57 incl	[1] 1.875	11.09 11.41	0.208 0.214	9.16
13	Aug 9	58–63 incl	[1] 1.275	13.26 12.55	0.169 0.160	10.99
75	Aug. 21	75	[3] 1.8015	13.77	0.248	9.86
GREEN OYSTER						
72	Aug. 16	72	[3] 1.1827	175.02	2.07	10.28
73	Aug. 17	73	[3] 1.0188	121.71	1.24	11.63
76	Aug. 29	76	[3] 1.8830	271.91	5.12	12.09
77	Aug. 30	77	[3] 1.2494	186.49	2.33	10.74
78	Aug. 30	78	[3] 1.2200	175.74	2.144	12.25
79	Aug. 31	79	[3] 1.0190	241.41	2.460	13.47

Note.—Closed chamber method used in experiments 10–13, inclusive. Open chamber method used in experiments 72–79, inclusive.

[1] Average weight of 6 oysters.

[2] Determinations were repeated wherever there was sufficient material.

[3] Weights of individual oysters.

SUMMARY

1. Two methods for the determination of oxygen consumption of the oyster were devised.

2. Oxygen consumption of normal oysters under standard conditions varies from 6.45 to 15.04 cubic centimeter per hour per 10 grams of dry weight.

3. Oxygen consumption is not influenced by oxygen tension when the amount of oxygen present is greater than 2.5 cubic centimeters per liter. Below this point oxygen consumption is affected by oxygen tension.

4. Changes in pH values such as can be brought about by the oyster under the conditions of the experiments and the accumulation of the products of its own metabolism do not alter its metabolic rate. The shell of the oyster acts as an efficient buffer, preventing the lowering of the pH below 6.0.

5. Low oxygen tension and variation in the pH values of water from 8.2 to 6.6 have no effect on the rate of flow of water through the gills.

6. Oxygen consumption of oysters can be increased by adding glucose to the water.

7. Green pigment of oysters is not a hemocyanin or copper proteinate of any kind. The compound exists in a highly dissociated state.

8. Copper content of normal oysters varies between 8.21 to 13.77 milligrams per 100 grams dry weight, or from 0.16 to 0.248 milligrams per oyster. Copper content of green oysters analyzed during the investigation varied between 121.71 and 271.91 milligrams per 100 grams dry weight, or from 1.24 to 5.12 milligrams per oyster.

9. Green oysters show a slight increase in oxygen consumption over normal oysters. The significance of this difference is, however, doubtful.

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THE BLOOD OF NORTH AMERICAN FRESH-WATER MUSSELS UNDER NORMAL AND ADVERSE CONDITIONS [1]

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INTRODUCTION

In the course of field studies on the mussel beds of the upper Mississippi, conducted during the past three years, considerable numbers of dead and dying mussels have been found in various localities once very productive of commercial shells. In addition, a large per cent of the glochidia, taken from female mussels living in the same areas, have been dead or diseased, indicating the existence of conditions which are reducing the natural reproduction of even such adult mussels as are able to withstand the environment. It is well established that progressive changes in stream conditions, resulting from the needs of navigation and from contamination through municipal and industrial wastes, have materially altered the natural habitats of the fresh-water mussels at many points in the Mississippi drainage. In order to evaluate the effects of these changes on the mussel fauna, particularly the effects of municipal and industrial wastes on the mussels themselves, a series of physiological studies on fresh-water mussels has been undertaken.

In the fresh-water mussels the blood is associated not only with nutrition, respiration, excretion, and the general well-being of the individual as in the higher animals, but the blood also has a special mechanical function in connection with the peculiar locomotion of fresh-water mussels. The "foot," the muscular organ of locomotion

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which is extruded between the valves of the shell, may be expanded during activity to many times its retracted volume by an inflowing of blood which can be held in the foot. A considerable volume of blood is required for this procedure and provision must be made for this fluid when the foot is retracted into the shell. Consequently the volume of blood in proportion to the size of the animal is large, and there are numerous sinuses—that is, reservoirs for blood—in various parts of the body. (See figs. 1, 2, 6, 7, and 8.)

Although no data are available for the exact total volume of the blood of fresh-water mussels, Weinland (1919) gives some figures on the relative weights of the shell, the soft parts, and the body fluid of the European fresh-water mussel, *Anodonta cygnea*, which are suggestive in this connection. He describes the fluid as that which could be drained or easily pressed from the soft parts of the animal, so his figures do not apply to blood alone, nor do they necessarily represent all of the blood; but the major portion of this fluid was blood. He found this body fluid as described to constitute from 46 to 57 per cent of the total weight of the animal, including the shell, or almost two and one-half times the weight of the drained soft parts.

In view of the large volume of blood in a fresh-water mussel and the importance of this fluid not only in the general metabolism but in the locomotion of the animal, the blood has been used as a starting point for the physiological studies of fresh-water mussels, as the blood is known to reflect the condition of the individual in both health and disease in the higher animals.

NORMAL BLOOD OF FRESH-WATER MUSSELS

METHOD OF TAKING SAMPLES

As the first task in these studies was the determination of the normal values for fresh-water mussel blood from which deviation as produced by various factors could be observed, only vigorous individuals taken directly from the water were used unless otherwise stated. All animals failing to give prompt and strong contractions of the pedal muscle and mantle margin, and in which the heart was not beating regularly when the valves were opened, were rejected from these groups of normals.

In taking blood for analyses care was used to avoid dilution with the water contained in the gill cavities of the animal. The two shells were opened gently with mussel tongs (Coker, Shira, Clark, and Howard, 1921), and the water allowed to drain out of the gill and mantle cavities. The two large muscles holding the valves together were then cut and one valve turned back, the exposed gill and mantle on that side being cut away. This procedure left the pericardial cavity intact but easily accessible. The animal was again drained free of any water or blood which might have accumulated in the mantle cavity during the operation. The pericardial cavity was then opened with a pair of small iridectomy scissors and the blood taken directly from the pulsating heart. It was found in actual practice that in an animal opened in this manner blood rapidly accumulated between the uninjured mantle and the shell, and several cubic centimeters of blood could be extracted by making a small opening near the center of the mantle on the uninjured side. Tests of the blood accumulating in this mantle pocket showed that, if taken immediately, this blood did not differ in composition from blood drawn directly from the heart, and consequently this blood could be used when large samples were desired. However, as most of the determinations required only small samples of blood, the blood was usually taken directly from the heart as described above.

If blood samples were to be taken from a single mussel over a period of days the procedure was modified. The outside of the shell was ground away on an emery wheel until the portion directly over the pericardial cavity was quite thin. This grinding was done little at a time, the mussel being immersed frequently in water to prevent heating of the shell. When the shell had been ground to a suitable thinness in the region desired a "window" was opened in the shell by means of small bone forceps and the pericardium exposed. The mussel did not seem to be greatly disturbed by this operation, and the heartbeats could be counted readily through the pericardium. Using a fine dental needle on a Leur syringe the pericardium was punctured and blood drawn directly from the heart. After removing the needle the heart continued to beat regularly and animals so prepared were kept alive for a period of days, although samples of blood were drawn daily or at even shorter intervals.

GENERAL PHYSICAL PROPERTIES

The blood of the species of North American fresh-water mussels studied is a mobile, limpid, lusterless fluid, clear and colorless when first drawn from the heart or sinuses, but soon becoming slightly turbid. Drawn blood does not clot into a solid mass, but in from one to five minutes after the blood is removed from the body of the mussel, particles of a whitish, opaque coagulum appear, suspended like bits of curd in the more watery, uncoagulated fluid. These pieces of coagulum which agglutinate to some extent form only a small portion of the total volume. On heating to 50° C. or above, the separation of the coagulum proceeds more rapidly and as this albuminous precipitate settles to the bottom of the container the supernatant fluid becomes clear and sparkling. Dried mussel blood has a very faint, yellowish-brown color, which deepens on heating or on prolonged exposure to the air.

SPECIFIC GRAVITY

The specific gravity of the blood was determined by the Barbour and Hamilton (1926) falling-drop method. As this procedure requires only 0.01 cubic centimeter of blood, usually three or more determinations were made each time a sample was taken, and the values averaged.

In Table 1 the summarized data on specific gravity of the blood from 145 individual mussels, representing 19 species, are given. Only animals which appeared to be in good condition and which had not been subjected to experimentation were incorporated in this series. The determinations grouped in Table 1 include readings made in every month of the year and from both male and female mussels (see Table 2 for individual data) in order to obtain the average normal limits of variation in blood values.

The average specific gravity was 1.0026—a very low value for blood when compared with the specific gravity of the blood of man, the pigeon, and common fresh-water animals (see Table 3). Even the maximum specific gravity given in Table 1, 1.0078, and the maximum specific gravity of the blood from any mussel under experimental conditions in these studies, 1.0099 (from a moribund specimen of *Quadrula metanevra;* see Table 17), are well below the values commonly recorded for the blood specific gravity of animals other than fresh-water mussels.

TABLE 1.—*Specific gravity of blood of fresh-water mussels*

Scientific name	Common name	Number of individuals	Blood—specific gravity										
			1.0000–1.0010	1.0011–1.0020	1.0021–1.0030	1.0031–1.0040	1.0041–1.0050	1.0051–1.0060	1.0061–1.0070	1.0071–1.0080	Minimum	Average	Maximum
Subfamily Unioninæ:													
Fusconaia ebena	Niggerhead	4	-----	-----	-----	-----	3	1	-----	-----	1.0043	1.0048	1.0057
Fusconaia undata	Pig toe	7	-----	1	1	3	1	-----	1	-----	1.0018	1.0036	1.0052
Tritogonia verrucosa	Buckhorn	7	-----	2	4	1	-----	-----	-----	-----	1.0011	1.0023	1.0031
Amblema costata	Three-ridge	6	-----	-----	2	2	1	1	-----	-----	1.0022	1.0034	1.0042
Quadrula pustulosa	Pimple back	1	-----	-----	-----	-----	1	-----	-----	-----	-------	1.0043	-------
Quadrula metanevra	Monkey face	1	-----	-----	-----	-----	1	-----	-----	-----	-------	1.0043	-------
Unio popei	Pope's purple	2	-----	2	-----	-----	-----	-----	-----	-----	1.0016	1.0017	1.0019
Subfamily Anodontinæ:													
Anodonta limneana	Southern floater	3	-----	1	1	1	-----	-----	-----	-----	1.0016	1.0027	1.0034
Lasmigona compressa	Heel splitter	1	-----	-----	-----	1	-----	-----	-----	-----	-------	1.0032	-------
Subfamily Lampsilinæ:													
Obliquaria reflexa	Three-horned warty-back.	6	-----	2	1	2	1	-----	-----	-----	1.0017	1.0027	1.0043
Proptera alata	Pink heel splitter	12	-----	1	10	1	-----	-----	-----	-----	1.0011	1.0024	1.0031
Proptera lævissima	Paper shell	1	-----	-----	-----	1	-----	-----	-----	-----	-------	1.0036	-------
Plagiola lineolata	Butterfly	2	-----	1	1	-----	-----	-----	-----	-----	1.0013	1.0021	1.0028
Ligumia recta latissima	Black sand-shell	1	-----	-----	1	-----	-----	-----	-----	-----	-------	1.0026	-------
Lampsilis anodontoides	Yellow sand-shell	17	2	4	6	2	1	1	1	-----	1.0007	1.0027	1.0063
Lampsilis fallaciosa	Slough sand-shell	29	1	12	11	4	-----	1	-----	-----	1.0007	1.0024	1.0055
Lampsilis siliquoidea pepinensis.	Lake Pepin mucket	29	5	8	10	3	1	1	-----	1	1.0004	1.0024	1.0078
Lampsilis ventricosa	Pocketbook	1	-----	-----	1	-----	-----	-----	-----	-----	-------	1.0029	-------
Actinonaias carinata	River mucket	15	1	4	5	5	-----	-----	-----	-----	1.0003	1.0025	1.0043
Total	19 species	145	9	38	54	26	10	5	2	1	1.0003	[1] 1.0026	1.0078

[1] Average of all individuals.

TABLE 2.—*Individual specific gravity and pH data*

Date, species, and location	Specific gravity	pH
Niggerhead (Fusconaia ebena), Mississippi River, Nahant, Iowa:		
July 19, 1929	1.0043	7.6
Do	1.0044	7.7
Do	1.0049	7.5
Do	1.0057	------
Pig toe (Fusconaia undata), Mississippi River, Fairport, Iowa:		
July 15, 1929	1.0018	7.8
July 18, 1929	1.0026	7.7
July 17, 1929	1.0034	7.7
July 19, 1929	1.0037	7.6
July 13, 1929	1.0040	7.8
July 19, 1929	1.0043	7.7
Do	1.0052	------
Buckhorn (Tritogonia verrucosa), Mississippi River, Fairport, Iowa:		
Aug. 22, 1929	1.0011	7.5
July 26, 1929	1.0015	7.9
July 12, 1929	1.0021	7.8
July 25, 1929	1.0029	7.8
July 27, 1929	1.0029	8.1
Do	1.0029	7.9
Mar. 7, 1930	1.0031	------
Three-ridge (Amblema costata), Mississippi River, Fairport, Iowa:		
July 19, 1929	1.0022	7.5
Nov. 7, 1929	1.0027	7.7
July 19, 1929	1.0035	7.6
July 8, 1929	1.0036	7.9
July 19, 1929	1.0042	7.8
Do	1.0042	7.4
Pimple back (Quadrula pustulosa), Mississippi River, Nahant, Iowa:		
July 19, 1929	1.0043	7.6
Monkey face (Quadrula metanevra), Mississippi River, Nahant, Iowa:		
July 19, 1929	1.0043	7.7
Pope's purple (Unio popei), canals from Rio Grande, Mercedes, Tex.:		
May 21, 1929	1.0016	8.3
May 27, 1929	1.0019	8.1
Apr. 25, 1929	--------	7.7
June 3, 1929	--------	8.1
Southern floater (Anodonta limneana), canals from Rio Grande, Mercedes, Tex.:		
Mar. 24, 1930	1.0016	7.8
Mar. 10, 1930	1.0021	8.0
Mar. 27, 1930	1.0034	8.0
Squaw foot (Strophitus rugosus), Mississippi River, Fairport, Iowa:		
June 27, 1929	--------	8.3
Heel splitter (Lasmigona compressa), Mississippi River, Fairport, Iowa:		
July 10, 1929	1.0032	7.9
Three-horned warty-back (Obliquaria reflexa), Mississippi River, Fairport, Iowa:		
Aug. 28, 1929	1.0017	8.0
Aug. 27, 1929	1.0018	7.9
Aug. 26, 1929	1.0021	7.9
Do	1.0031	7.8
Aug. 27, 1929	1.0032	8.0
Do	1.0043	7.8
Pink heel splitter (Proptera alata), Mississippi River, Fairport, Iowa:		
Mar. 4, 1930	1.0011	8.0
Do	1.0021	7.9
Aug. 24, 1929	1.0021	7.7
Do	1.0022	8.0
Do	1.0022	8.0
Aug. 23, 1929	1.0025	7.9
Do	1.0026	8.0
Do	1.0026	7.9
Do	1.0027	7.8
Aug. 24, 1929	1.0028	7.9
Aug. 26, 1929	1.0029	8.0
Aug. 22, 1929	1.0031	8.0
Paper shell (Proptera laevissima), Mississippi River, Nahant, Iowa:		
July 19, 1929	1.0036	7.7
Butterfly (Plagiola lineolata), White River, Newport, Ark.:		
Mar. 20, 1930	1.0013	7.9
Mar. 27, 1930	1.0028	7.9
Black sand-shell (Ligumia recta latissima), Mississippi River, Fairport, Iowa:		
Mar. 4, 1930	1.0026	7.7

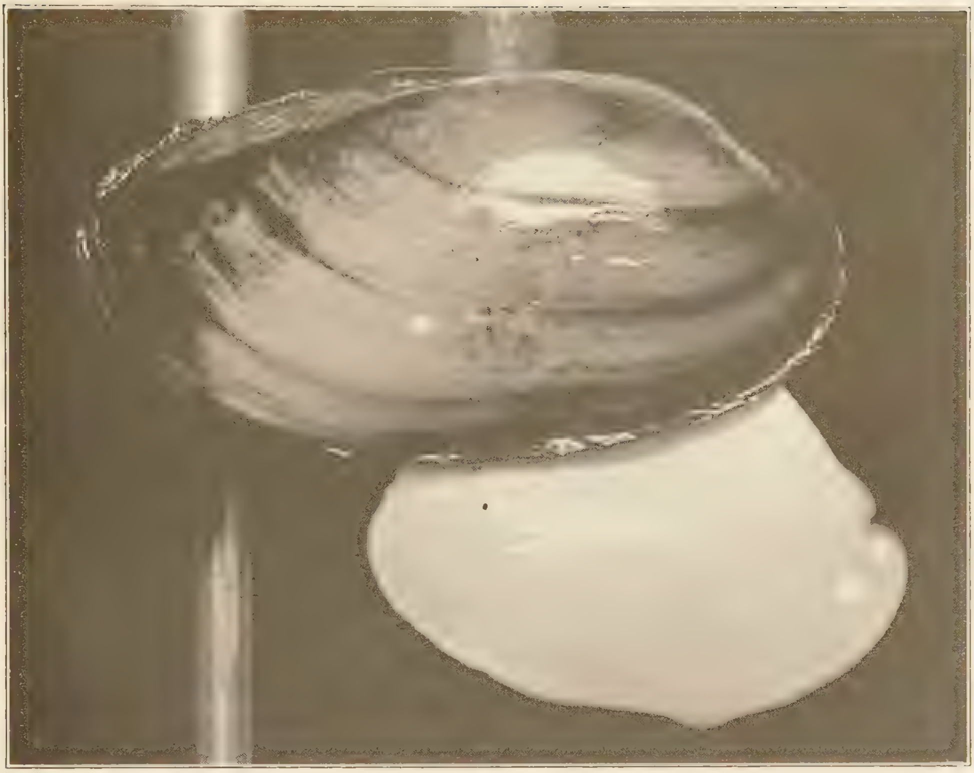

Figure 1.—*Lampsilis anodontoides*, yellow sand-shell, natural size. Living animal with foot completely extruded showing the relatively large volume of this organ and the demand such expansion makes on the blood and body fluids. The animal is supported on the far side by a glass rod attached to the valve of the shell by beeswax

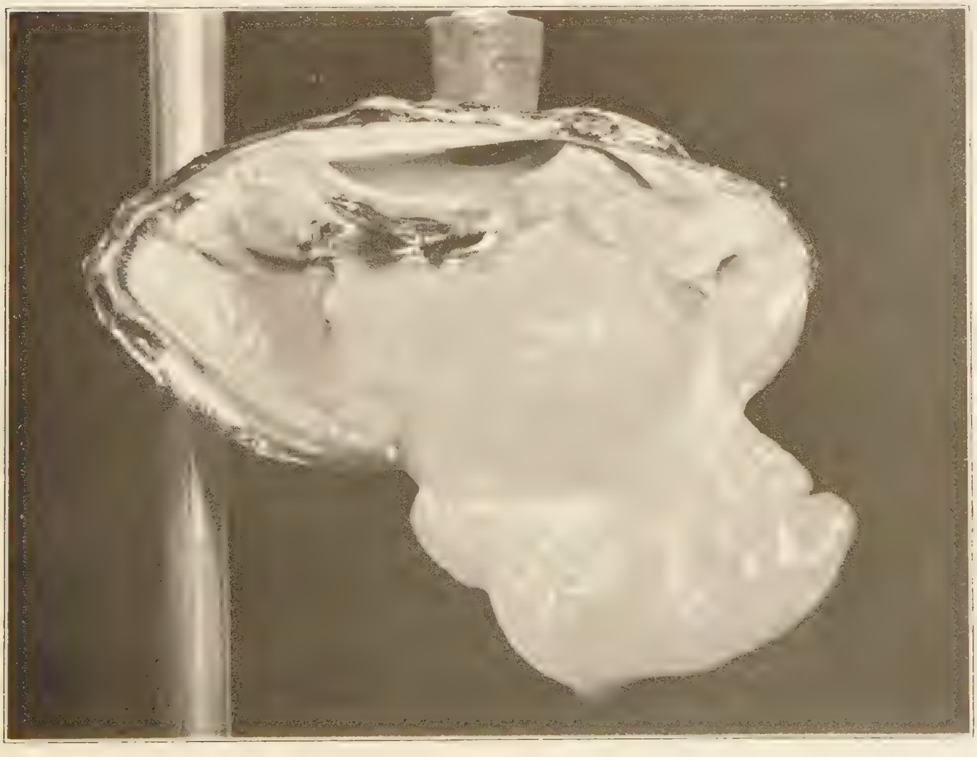

Figure 2.—*Lampsilis anodontoides*, yellow sand-shell. Living animal (same as Fig. 1) with one valve of shell removed to show size and position of foot. Heart may be seen just below the open space near middle of the hinge

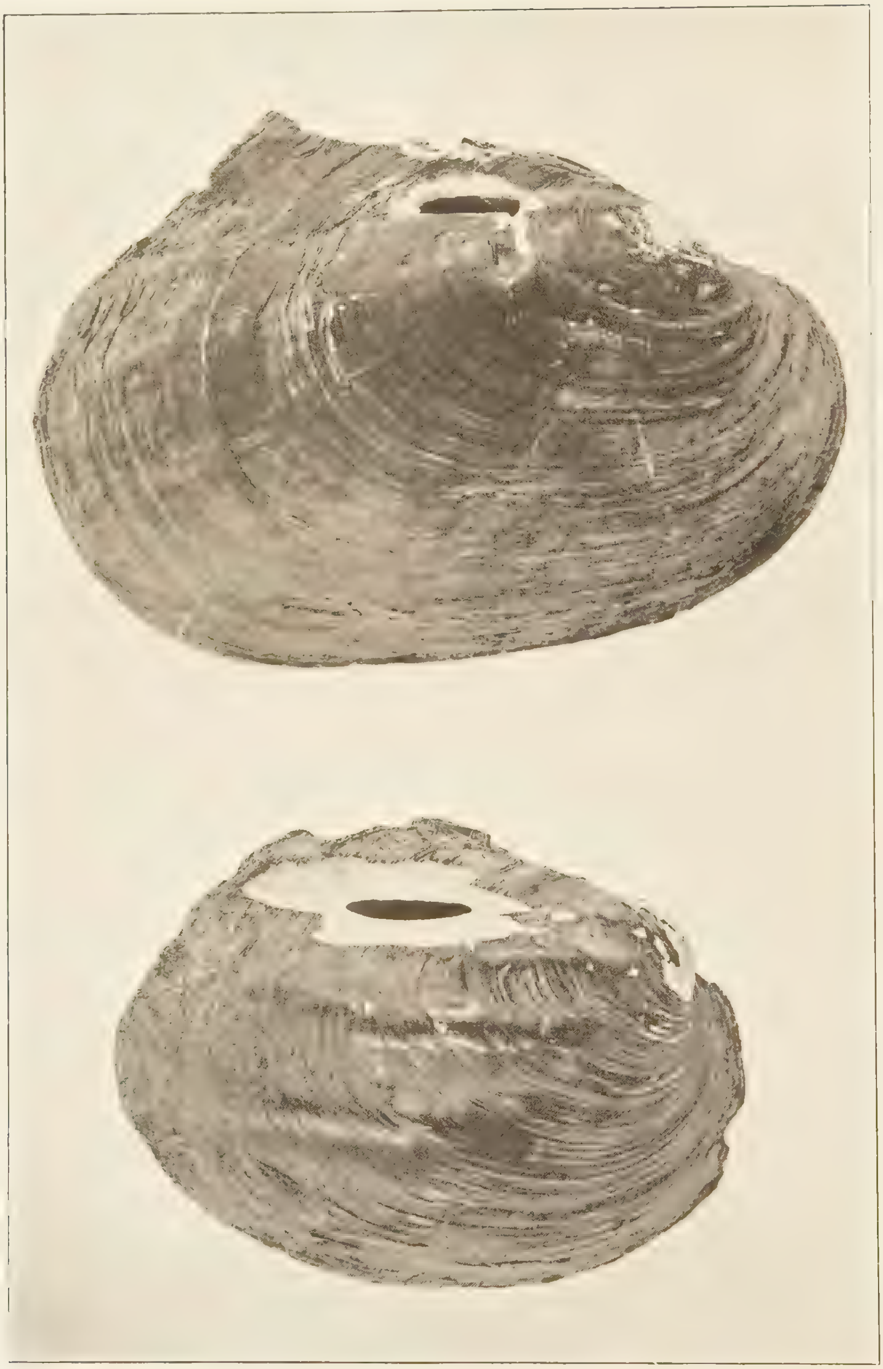

Figure 3.—Shells of *Proptera alata*, pink heelsplitter (upper), and *Amblema costata*, three-ridge (lower), with "windows" ground in the valves to expose pericardium and heart. Through such windows numerous blood samples could be drawn from a single individual, as animals so prepared often lived for a week or more

TABLE 2.—*Individual specific gravity and pH data*—Continued

Date, species, and location	Specific gravity	pH
Yellow sand-shell (Lampsilis anodontoides), canals from Rio Grande, Mercedes, Tex.:		
Apr. 4, 1929	1.0007	8.0
Apr. 22, 1929	1.0010	8.0
Apr. 16, 1929	1.0011	8.3
Mar. 10, 1930	1.0016	8.0
Mar. 26, 1930	1.0018	------
Mar. 27, 1930	1.0020	7.9
May 6, 1929	1.0024	7.9
Mar. 25, 1930	1.0024	------
Mar. 10, 1930	1.0024	8.0
Feb. 21, 1930	1.0024	------
Feb. 24, 1930	1.0026	7.7
May 9, 1929	1.0026	8.0
Apr. 30, 1929	1.0035	7.8
Mar. 17, 1930	1.0036	7.8
Apr. 18, 1929	1.0049	7.6
May 2, 1929	1.0053	7.7
Apr. 8, 1929	1.0063	8.1
Apr. 26, 1929	---------	7.9
Apr. 16, 1929	---------	7.9
May 29, 1929	---------	8.2
Slough sand-shell (Lampsilis fallaciosa), Mississippi River, Fairport, Iowa:		
July 2, 1929	1.0007	7.8
July 31, 1929	1.0015	7.9
Aug. 10, 1929	1.0015	8.1
Aug. 19, 1929	1.0015	8.2
Aug. 12, 1929	1.0017	8.1
Aug. 19, 1929	1.0017	7.7
Aug. 2, 1929	1.0017	------
Aug. 7, 1929	1.0018	7.8
Aug. 19, 1929	1.0019	8.0
Aug. 8, 1929	1.0019	7.8
Aug. 4, 1929	1.0019	8.1
Aug. 13, 1929	1.0020	8.1
Aug. 5, 1929	1.0021	7.7
Aug. 9, 1929	1.0021	8.1
Aug. 3, 1929	1.0022	7.7
Aug. 15, 1929	1.0022	8.1
Aug. 9, 1929	1.0022	8.0
Aug. 29, 1929	1.0023	7.9
Aug. 16, 1929	1.0024	8.1
Aug. 21, 1929	1.0025	8.1
Aug. 22, 1929	1.0025	8.1
Aug. 12, 1929	1.0026	------
Aug. 1, 1929	1.0028	8.0
Aug. 14, 1929	1.0029	8.0
July 30, 1929	1.0032	7.8
Aug. 16, 1929	1.0036	8.2
Aug. 6, 1929	1.0037	7.9
Aug. 21, 1929	1.0038	7.8
Aug. 17, 1929	1.0055	8.2
Lake Pepin mucket (Lampsilis siliquoidea pepinensis), Lake Pepin, Minn.:		
Jan. 3, 1930	1.0004	7.9
Do	1.0006	7.9
Jan. 8, 1930	1.0008	7.9
Jan. 6, 1930	1.0009	7.9
Apr. 1, 1929	1.0009	7.7
Dec. 17, 1929	1.0012	8.0
Nov. 18, 1929	1.0012	7.7
June 4, 1929	1.0015	8.1
Nov. 20, 1929	1.0016	------
May 20, 1929	1.0019	8.3
Apr. 15, 1929	1.0020	8.0
Jan. 6, 1930	1.0020	7.9
Nov. 20, 1929	1.0020	------
Dec. 16, 1929	1.0022	8.0
Do	1.0023	7.7
Oct. 4, 1929	1.0025	------
Oct. 9, 1929	1.0026	7.8
Jan. 3, 1930	1.0026	7.6
May 23, 1929	1.0026	8.5
Oct. 9, 1929	1.0026	7.8
Jan. 3, 1930	1.0027	7.6
May 20, 1929	1.0029	8.2
June 7, 1929	1.0029	7.7
Oct. 3, 1929	1.0035	7.6
Oct. 1, 1929	1.0036	7.9
Oct. 9, 1929	1.0038	7.9
Do	1.0041	7.9
Apr. 29, 1929	1.0052	8.0
May 20, 1929	1.0078	8.1
Pocketbook (Lampsilis ventricosa), Mississippi River, Fairport, Iowa:		
July 5, 1929	1.0029	8.2
River mucket (Actinonaias carinata), Fox River, Millington, Ill.:		
May 7, 1929	1.0003	8.1
June 10, 1929	1.0015	7.8
Nov. 18, 1929	1.0018	8.0
May 3, 1929	1.0020	8.0
Oct. 30, 1929	1.0020	7.7
Apr. 1, 1929	1.0021	8.5
Apr. 4, 1929	1.0021	7.8
May 20, 1929	1.0022	8.3
Oct. 4, 1929	1.0023	7.9
Oct. 30, 1929	1.0024	7.9
Apr. 11, 1929	1.0032	7.9
Mar. 26, 1929	1.0034	7.9
Do	1.0039	8.4
Oct. 28, 1929	1.0039	7.7
Mar. 28, 1929	1.0043	8.2
Apr. 2, 1929	---------	8.4
Apr. 9, 1929	---------	7.8

TABLE 3.—*Comparison of specific gravity of the blood of fresh-water mussels with that of other bloods*

[All determinations made by the falling drop method]

Species	Common name	Specific gravity average	Number of cases	Locality
Homo sapiens	Man	1.0550	---------	Columbia, Mo.
Columba livia var	Street pigeon	1.0494	12	Do.
Chrysemys belli	Bell's painted turtle	1.0328	7	North Judson, Ind.
Rana pipiens	Leopard frog	1.0271	3	Do.
Icthyobus cyprinella	Largemouth buffalo fish	1.0317	1	Fairport, Iowa.
Ictalurus punctatus	Spotted catfish	1.0260	6	Do.
Lepisosteus platostomus	Short-nosed gar	1.0469	6	Do.
Cambarus virilis	Crawfish	1.0185	10	Hahatonka, Mo.
Unionidæ, 19 species	Fresh-water mussels	1.0026	145	Mississippi and Rio Grande drainages.

The corpuscles of the blood are of course an important factor in these comparisons of blood specific gravity. The blood of the fresh-water mussel does not contain pigmented, oxygen-carrying corpuscles of the red blood corpuscle type found in large numbers in the blood of vertebrates, although there are small numbers of amœbocytes or white blood corpuscles in the blood of fresh-water mussels. As the red blood corpuscles have an average specific gravity of 1.0880 (Krüger, 1925), it would seem that a fairer comparison for mussel blood would be one with the plasma or serum of vertebrates. The average specific gravity values for the serum or plasma of various vertebrates lie between 1.0170 and 1.0309 (Krüger, 1925), and the specific gravity of the whole blood of the Japanese oyster, *Ostrea circumpicta* Pillsbury, which like the blood of the fresh-water mussels contains no red blood corpuscles, is between 1.0230 and 1.0280 according to Yazaki (1929). It is evident, therefore, that the low specific gravity of the blood of the fresh-water mussels is not due entirely to the absence of red blood corpuscles, since the specific gravity of the blood of the oyster is essentially the same as that of the serum or plasma of vertebrate blood.

From the distribution of the individual species in Table 1, and from the experimental tests (v. i.) the average range or normal variation in the specific gravity of the blood of the fresh-water mussels studied seems to lie between 1.0010 and 1.0050, a variation of 0.0040 and a deviation of −0.0016 to +0.0024 from the average of 1.0026. Stebbins and Leake (1927), using the Barbour method, report the diurnal variation in the specific gravity of the blood of dogs as 0.0044, of men as 0.0033, and of women as 0.0027. The actual variation in the specific gravity of the blood of fresh-water mussels is therefore of much the same magnitude as that of dogs and man, but the proportional change resulting from this variation is very much greater in the case of the mussel blood with an average specific gravity of 1.0026 than in human blood with an average specific gravity near 1.0554.

Although fewer specimens of *Unioninæ* than of *Lampsilinæ*, are included in Table 1, the grouping of the individual cases suggest that the *Unioninæ* have blood of a slightly higher specific gravity than the *Lampsilinæ*. Averaging the specific gravities from these two groups in Table 1 separately, the average specific gravity of the blood for all species of *Unioninæ* studied falls between 1.0030 and 1.0040 and that for all *Lampsilinæ* between 1.0020 and 1.0030. Differences found in experimental tests also show this same division of species on the basis of the specific gravity of the blood.

TOTAL SOLIDS AND ASH

The per cents of total solids and of ash contained in the blood were determined for four species of North American fresh-water mussels, the pink heelsplitter, *Proptera alata* (Say); the slop bucket, *Anodonta corpulenta* Cooper; the Lake Pepin mucket, *Lampsilis siliquoidea pepinensis* Baker; and the heelsplitter, *Lasmigona compressa* (Lea). For each species, the blood from several individuals was collected into a weighed pyrex beaker until a sample of 100 cubic centimeters or more was obtained. The beakers were then reweighed, and the blood slowly evaporated to dryness at temperatures below 60° C. The solid residues in the beakers were desiccated at 90°–105° C. in an electric drying oven, cooled over sulphuric acid, and weighed. Each residue was divided into convenient samples (0.3 to 0.5 gram), which were ignited in a platinum dish at a dull red heat and the ash brought to a constant weight. The per cent of total solids and of ash in the blood are given in Table 4.

TABLE 4.—*Per cent of total solids and ash in the blood of four species of North American fresh-water mussels, together with total solids and ash in the blood of other animals appended for comparisons*

Scientific name	Common name	Fluid used	Per cent of total solids	Per cent of ash	Ratio of total solids to ash	Locality or authority
Anodonta corpulenta	Slop bucket	Whole blood	0.3436	0.1256	100 : 37	Fairport, Iowa.[1]
Lasmigona compressa	Heel splitter	do	.4965	.1505	100 : 30	Do.
Proptera alata	Pink heel splitter	do	.4500	.1573	100 : 35	Do.
Lampsilis siliquoidea pepinensis	Lake Pepin mucket	do	.4140	.1820	100 : 44	Lynchville, Wis.[2]
Averages			.4260	.1539	100 : 36	
Anodonta cygnea	European fresh-water mussel.	do	.8540	.2600	100 : 30	Schmidt, 1845.
Anodonta and Unio	do	do	.3110	.1890	100 : 61	Voit, 1860.
Octopus macrops	Octopus	do	12.0300	2.9700	100 : 25	Bottazzi, 1911.
Saxidomus nuttali	Marine rock clam	do	4.3300	2.8000	100 : 70	Myers, 1920.
Schizothaerus nuttali	Washington clam	do	4.2080	3.2900	100 : 80	Do.
Pecten sp	Scallop	do	1.7300	1.0100	100 : 58	Griffiths, 1892
Solen sp	Razor clam	do	1.7300	.9900	100 : 57	Do.
Mya sp	Soft-shell clam	do	1.6400	.9900	100 : 60	Do.
Helix pomatia	Edible snail	do	3.9000	.3000	100 : 8	Couvreur, 1900.
Astacus fluviatilis	European crayfish	do	4.8600	1.1300	100 : 23	Halliburton, 1885.
Cyprinus carpio	German carp	do	13.4300			Krüger, 1925.
Do	do	Serum	5.2000			Do.
Equus caballus	Horse	Whole blood	25.0980	1.0480	100 : 5	Abderhalden, 1911.
Do	do	Serum	9.7950	0.8890	100 : 90	Do.

[1] July 6, 1929.

[2] Oct. 10, 1929.

The total solids found in these samples of fresh-water mussel blood varied from 0.344 to 0.497 per cent, around an average of 0.426 per cent of the weight of the blood. These values lie between the two determinations given for European fresh-water mussels—that of Schmidt (1845) being 0.845 per cent for *Anodonta cygnea* and that of Voit (1860) 0.311 per cent for both *Anodonta sp.* and *Unio sp.*—and if compared with the total solids found in the blood of various other animals, both vertebrate and invertebrate (see Table 4), show the fresh-water mussels to have a very dilute blood. In addition to the animals listed in Table 4, the writers in reviewing the existing literature on blood solids have checked some 60 species of animals in all without finding any one having as low total blood solids as the fresh-water mussels (for general lists see Winterstein, 1925; and Fürth, 1903). Relatively high total solids are the rule in vertebrate blood because of the large numbers of red blood corpuscles, not found in fresh-water mussel blood; but even the sera of vertebrate blood and the whole blood of invertebrates contain much larger amounts of solids than fresh-water mussel blood.

As the total solids contained in any blood determine the osmotic pressure of the fluid of the blood, and are of large importance therefore in regulating the water and salt balance in the living tissues of the animal, the very low total solids of fresh-water mussel blood suggest a rather close adjustment between the living tissue of the fresh-water mussel and the fluid environment in which these animals live. Such an adjustment, accomplished through the blood, was established (v. i.) in the experimental tests in fresh-water mussels.

Considering the low total solids of the fresh-water mussel blood in connection with their habitat of fresh-water—that is, a medium with a relatively low osmotic pressure—the low total solids of the soft-shell clam, *Mya sp.*, are of interest, both because the fresh-water mussels are regarded as having evolved from shore-dwelling marine forms and because *Mya* is an inhabitant of gravelly mud flats at the mouths of rivers (Rogers, 1913), where the salinity of the water would be subject to some modification by the outbound fresh-water.

The average values for the ash of the blood—that is, the inorganic constituents—of the four species of fresh-water mussels examined, were 0.1539 per cent of the weight of the blood, or a little more than one-third of the weight of the total solids. Because of the low values of the total solids the average per cent of ash in the blood of fresh-water mussels is of course much below the ash content of the blood of the vertebrates or of most invertebrates.

The ratio of ash to total solids in the blood, which is an expression of the relative amount of organic substances in the blood, varies widely in the several groups of animals. (See Table 4.) As the total solids of the fresh-water mussel blood are much lower than those of other bloods, the actual per cent of organic solids in the blood of the fresh-water mussels is of necessity also much lower than that of other bloods. Considering the relative amount of organic constituents, however, the fresh-water mussel blood falls about midway between vertebrate serum or plasma on the one hand and vertebrate whole blood on the other; that is, the fresh-water mussels are near the middle of the invertebrate group when this organic-inorganic solids ratio is considered.

The low total solids and the moderately high ratio of ash to total solids in the blood of the fresh-water mussels show this blood to be a very watery fluid, in which the low specific gravity indicates a small quantity of solids in solution or suspension rather than a mixture containing salts, in amounts comparable to those found in the blood of other animals, together with sufficient other substances lighter than water to produce the low specific gravity as found.

BLOOD SUGAR

Blood sugar, the only organic constituent of the blood considered separately, was determined by the Hagedorn-Jensen (1923) iodine titration method for 10 species of fresh-water mussels. (See Table 5.) The blood sugar averaged 31 milligrams per 100 cubic centimeters of blood, in these species, ranging from 7 to 93 milligrams per 100 cubic centimeters of blood. The average value and the range of variation are much the same as those for many other invertebrates, both marine and fresh water, in spite of the fact that the total solids and the inorganic salts are much lower in fresh-water mussel blood than in other invertebrates. Considering these 10 species of fresh-water mussels separately the variation between species was not considered significant as it was no greater than that between individuals of the same species in several cases. This wide variation in blood-sugar levels between individuals of the same species is perhaps the most striking feature in Table 5, but it is not without its parallel in other species of mollusks. Lang and Macleod (1920) report the blood sugar of the marine clam *Schizothaerus nuttali* as from 1.5 to 1.8 milligrams per 100 cubic centimeters, and Myers (1920) found 74 milligrams of blood sugar per 100 cubic centimeters in the same species; and according to the observations of Couvreur and Bellion (1907, 1908) and Sellier (1907, 1908), the amount and the type of sugar in the blood of the snail *Helix pomatia*, varies with the state of activity of the animal. It seems, therefore, that the blood sugar values of the fresh-water mussels do not differ materially either in average or in range from those of other mollusca, even though the blood of the fresh-water mussels is very dilute.

TABLE 5.—*Average blood sugar values for 10 species of fresh-water mussels*

Scientific name	Common name	Number of specimens	Number of determinations	Blood sugar in milligrams per 100 cubic centimeters of blood		
				Minimum	Average	Maximum
Tritogonia verrucosa	Buckhorn	2	6	34	58	74
Quadrula pustulosa	Pimple back	1	3	20	28	34
Quadrula quadrula	Maple leaf	1	3	20	23	25
Elliptio dilatatus	Lady finger	1	3	34	37	43
Anodonta limneana	Southern floater	6	14	7	16	61
Strophitus rugosus	Squaw foot	1	3	8	16	20
Obliquaria reflexa	Three-horned warty-back	1	3	20	28	43
Proptera alata	Pink heel splitter	2	6	34	47	65
Lampsilis anodontoides	Yellow sand-shell	6	18	8	48	93
Lampsilis siliquoidea pepinensis	Lake Pepin mucket	1	3	10	17	22
Total		22	62		32	

INORGANIC SALTS

Since the pioneer work of Ringer (1882) on the inorganic salts of the blood, it has become well established that the chief inorganic salt of the blood of all animals is sodium chloride, and that in physiological balance with this salt are much smaller quantities of potassium and calcium salts, usually the chlorides. As qualitative tests on the blood of the species of North American mussels under consideration showed the presence of sodium, potassium, calcium, and magnesium, determinations of blood sodium by the pyroantimoniate method of Kramer and Tisdale (1921) and of the blood calcium by the oxalate method of Clark (1921) were made, the potassium-magnesium fraction being computed by difference. The data from these determinations are listed in Table 6.

The range between the maximum and minimum for both the sodium chloride and calcium chloride in the mussel blood was large when compared with the variation in these salts tolerated in dog blood or human blood, and it was only through the experimental tests (v. i.) that a satisfactory explanation of this variation in mussel blood was obtained. Without going into the experimental data here, it may be stated that it was found that the salt content of the blood of fresh-water mussels could be modified by the activity of the animal and by the environment in which the animal was held. The values in Table 6 represent, for the most part, blood from mussels just removed from the water; and as it was noted that a considerable concentration of the blood could be effected by the animal when the mussel was merely kept in the air for a time, the average values in Table 6 are lower than might be expected from the maximum values given there.

TABLE 6.—*Per cent of sodium, calcium, and other salts in the blood of fresh-water mussels*

Scientific name	Common name	Sodium as sodium chloride, per cent of whole blood			Calcium as calcium chloride, per cent of whole blood			Potassium, magnesium and other salts by difference, average	Total ash, averag
		Minimum	Average	Maximum	Minimum	Average	Maximum		
Anodonta corpulenta	Slop bucket	0. 0310	0. 1013	0. 2210	0. 0087	0. 0187	0. 0825	0. 0056	0. 1256
Lasmigona compressa	Heel splitter	. 0505	. 1092	. 2289	. 0103	. 0404	. 0859	. 0009	. 1496
Proptera alata	Pink heel splitter	. 0469	. 1144	. 2778	. 0130	. 0225	. 1060	. 0204	. 1573
Lampsilis siliquoidea pepinensis	Lake Pepin mucket	. 0964	. 1125	. 2950					. 1820
Average			. 1093			. 0272		. 0090	. 1539

NOTE.—Figures in this table are from 60 determinations.

The actual values of sodium chloride in the mussel blood are very low in comparison with the sodium chloride content of the blood of most animals, averaging between 0.1 and 0.2 per cent in the fresh-water mussels as against nearly 0.9 per cent in the blood of man and the mammals. The sodium chloride values for the blood of these North American species of mussels are comparable, however, with the salt values computed for the blood of European mussels. Philippson, Hannevart, and Thieren (1910) computed the sodium chloride content of the blood of *Anodonta cygnea* on the basis of the electroconductivity, and found it to represent about 0.2 per cent sodium chloride; and Fredericq (1899) and Monti (1914) give values for the depression of the freezing point of the blood of both *Unio* and *Anodonta* which would approximate 0.2 to 0.3 per cent sodium chloride.

The average calcium values in the fresh-water mussel blood are about the same as those for mammalian blood, in spite of the low salt content of the mussel blood; that is, the ratio of calcium to sodium is much higher in mussel blood than in mammalian blood. The maximum calcium per cent in mussel blood greatly exceed the calcium content of mammalian blood. This is not surprising, however, when it is considered that the calcium needs of the mussel are large in connection with the building and maintenance of a calcareous shell; and Collip (1920) has pointed out that, in the case of the marine clam *Mya arenaria*, the calcium of the shell can be used as a buffer to maintain the proper level of the alkalinity in the blood and body tissues in the face of various metabolic disturbances.

By difference the potassium-magnesium fraction was low. This has been confirmed by experimental studies in which it was found that the tissues of the fresh-water mussel are quite sensitive to slight changes in the potassium content of the medium surrounding them.

HYDROGEN-ION CONCENTRATION AND BUFFER VALUES

The pH of the blood of 20 species of fresh-water mussels was determined colorimetrically by the Gillaspie (1926) method, brom-thymol blue and cresol red being the dyes most frequently employed. Blood for this purpose was taken immediately after opening the animal to avoid changes due to loss of carbon dioxide on exposure to air. No determinations were made on less than 1 cubic centimeter of blood, and the turbidity factor was checked by carrying a control tube of blood behind the standard dye tubes in the comparometer block.

Readings, taken in all months of the year and from both sexes of the various species studied (see Table 7), show the blood of the fresh-water mussels to be definitely alkaline in reaction and with a more alkaline pH value than that of the blood of the higher animals. The average of 142 specimens of fresh-water mussels was pH 7.9, the individual readings ranging from pH 7.4 to pH 8.5, with the range pH 7.6 to pH 8.3 including 94 per cent of the cases. It is difficult to compare the pH of the mussel blood with that of man because of several factors, but VanSlyke (1921) lists the average pH value for man as 7.4, with a range of pH 7 to pH 7.8 as the limits compatible with life. The figures are subject to certain limitations, but greater alkalinity of the mussel blood is evident. (See Table 7 and fig. 4.)

Table 7.—*Hydrogen-ion concentration of the blood of fresh-water mussels*

Scientific name	Common name	Number of individuals	pH values									
			7.4	7.5–7.6	7.7–7.8	7.9–8.0	8.1–8.2	8.3–8.4	8.5–8.6	Minimum	Average	Maximum
Subfamily *Unioninæ*:												
Fusconaia ebena	Niggerhead	3	-----	2	1	-----	-----	-----	-----	7.5	7.6	7.7
Fusconaia undata	Pig toe	6	-----	1	5	-----	-----	-----	-----	7.6	7.7	7.8
Tritogonia verrucosa	Buckhorn	6	-----	1	2	2	1	-----	-----	7.5	7.8	8.1
Amblema costata	Three-ridge	6	1	2	2	1	-----	-----	-----	7.4	7.6	7.9
Quadrula pustulosa	Pimple back	1	-----	1	-----	-----	-----	-----	-----	-----	7.6	-----
Quadrula metanevra	Monkey face	1	-----	-----	1	-----	-----	-----	-----	-----	7.7	-----
Unio popei	Pope's purple	4	-----	-----	1	-----	2	1	-----	7.7	8.1	8.3
Subfamily Anodontinæ:												
Anodonta limneana	Southern floater	3	-----	-----	1	2	-----	-----	-----	7.8	7.9	8.0
Strophitus rugosus	Squaw foot	1	-----	-----	-----	-----	-----	1	-----	-----	8.3	-----
Lasmigona compressa	Heel splitter	1	-----	-----	-----	1	-----	-----	-----	-----	7.9	-----
Subfamily Lampsilinæ:												
Obliquaria reflexa	Three-horned warty-back.	6	-----	-----	2	4	-----	-----	-----	7.8	7.9	8.0
Proptera alata	Pink heel splitter	12	-----	-----	2	10	-----	-----	-----	7.7	7.9	8.0
Proptera laevissima	Paper shell	1	-----	-----	1	-----	-----	-----	-----	-----	7.7	-----
Plagiola lineolata	Butterfly	2	-----	-----	-----	2	-----	-----	-----	7.9	7.9	7.9
Ligumia recta latissima	Black sand shell	1	-----	-----	1	-----	-----	-----	-----	-----	7.7	-----
Lampsilis anodontoides	Yellow sand-shell	17	-----	1	4	9	2	1	-----	7.6	7.9	8.3
Lampsilis fallaciosa	Slough sand-shell	27	-----	-----	8	7	12	-----	-----	7.7	8.0	8.2
Lampsilis siliquoidea pepinensis	Lake Pepin mucket	26	-----	3	6	12	3	1	1	7.6	7.9	8.5
Lampsilis ventricosa	Pocketbook	1	-----	-----	-----	-----	1	-----	-----	-----	8.2	-----
Actinonaias carinata	River mucket	17	-----	-----	5	6	2	3	1	7.7	8.0	8.5
Total		142	1	11	42	56	23	7	2	7.4	[1] 7.9	8.5

[1] Average of all individuals.

The water from which the animals used in making the determinations listed in Table 7 were taken varied in pH value from 7.4 to 7.9, with an occasional value of pH 8. The average pH value of the water in the Mississippi River at Fairport, Iowa, just above an apparently healthy bed of mussels was pH 7.65, while that of the tank water in which mussels at Columbia, Mo., were kept varied throughout the year from pH 7.5 to pH 7.8. When compared with the environment the pH of the mussel blood was consistently a little more alkaline than the surrounding water, if the animals were kept well aerated and in average normal condition.

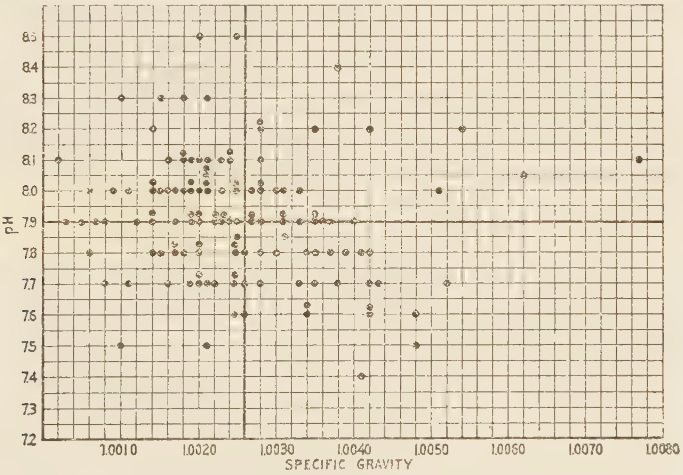

Figure 4.—Specific gravity plotted against pH, for normal blood of fresh-water mussels, showing trend away from alkalinity toward neutrality with an increase in specific gravity. This trend was also evident in blood of the mussels in the series exposed to air (v. i.). Average specific gravity (1.0026) and average pH (pH 7.9) are indicated by heavy lines

This observation is of interest in connection with the fact that the calcium content of the mussel blood is high and that the mussel blood is a medium which must transport relatively large quantities of calcium in connection with the production of the shell.

Collip (1920) has stated that in the marine clam, *Mya arenaria*, the calcium carbonate of the shell is available for the animal as an almost unlimited source of buffer material, so that the carbon dioxide produced during the activity of the animal could unite with the calcium carbonate of the shell, forming a bicarbonate which is freely soluble and alkaline in reaction. In the event that the carbon dioxide could not be removed promptly from the body of the animal, as during periods when the animal is removed from the water or while it has its shell closed tightly even though still in the water, the carbon dioxide produced could be buffered down and the alkaline value of the blood maintained. This explains the absence of acid values for the pH of the blood of fresh-water mussels which were held in air in a closed condition for several hours (v. i.). There is evidence (v. i.) that the closed mussels continue to use the oxygen in the water contained in the shell when tightly closed, and that this buffering out of the carbon dioxide formed during the absence of fresh circulating water from the outside by the calcium carbonate of the shell, makes possible the utilization of the oxygen contained. (See salt experiments.)

Another check on this point of the buffering value of the shell in the closed animals was made by titration of the buffer value of the blood, in terms of N/44 hydrochloric acid, for mussels just removed from the water and in which the blood was presumably well aerated. These values given in Table 8 show that the buffer value of the blood is quite low, and as there are only small amounts of proteins and other organic buffers in the blood of the fresh-water mussels this buffer value must be due very largely to the inorganic carbonates present. It has been noted previously in this discussion that the salt-ash content of the blood of the fresh-water mussels just removed from the water was lower than that of those animals which had been held out of water for some time. Part of this rise in salt content is due to a concentration of the blood—that is, a water loss; but part of it may also be due to the addition of calcium carbonate to the blood, withdrawn from the shell to buffer down the carbon dioxide formed. Collip (loc. cit.) found an increase in the calcium content of his marine clams under such conditions.

TABLE 8.—*Buffer values of the blood of fresh-water mussels*

[Cubic centimeters of N/44 hydrochloric acid required to titrate 5 cubic centimeters of blood]

Scientific name	Common name	N/44 hydrochloric acid cubic centimeters
Lampsilis anodontoides	Yellow sand-shell	1.05
Do	do	1.05
Average		1.05
Actinonais carinata	River mucket	1.03
Do	do	1.05
Actinonais carinata	River mucket	1.15
Do	do	1.20
Do	do	1.35
Do	do	1.35
Average		1.18

BLOOD GASES

As the carbon dioxide of the blood seems so definitely tied up with the salt content of the blood, particularly the calcium content, analyses for blood gases were made with the Van Slyke apparatus (1917) immediately after the mussels were taken from the water. Determinations for oxygen, carbon dioxide, and nitrogen were made,

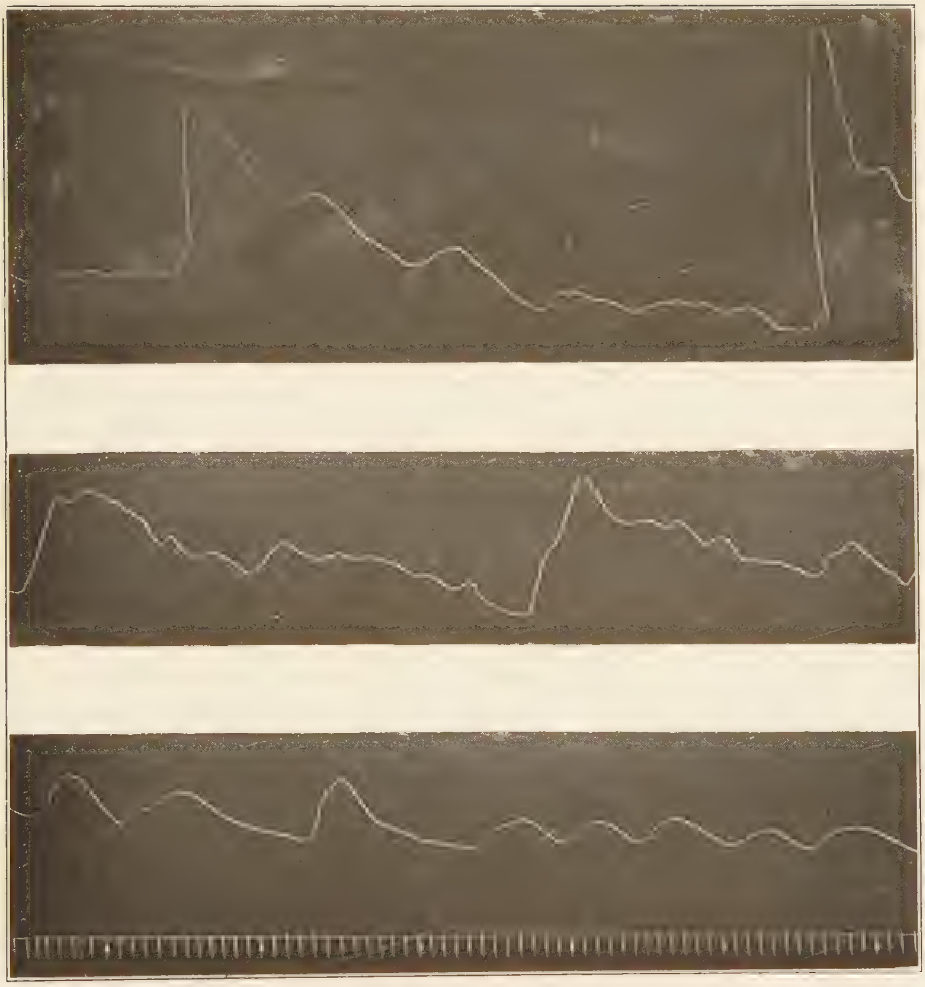

FIGURE 5.—Tracings of "foot strips" from fresh-water mussels showing the two types of contraction waves which pass over the foot continuously. Upper record from foot of *Proptera alata*, the pink heelsplitter; middle record from foot of *Unio popeii*, Pope's purple; lower record from foot of *Lampsilis anodontoides*, the yellow sand-shell. Time at bottom of record; single strokes, five seconds each; double strokes, minutes

and the results are tabulated in Table 9. As might be expected of a blood without pigmented, oxygen-carrying corpuscles, and with a very low total solids content, the volume of blood gas was small. When compared with the blood of marine bivalves (Cuenot, 1901; Winterstein, 1909), the oxygen and nitrogen values of the blood of the fresh-water mussels and some of the marine clams are found to be much the same, but the carbon dioxide content of the blood of the fresh-water mussel is much lower than that of the marine clams cited above or of the Japanese oyster, as determined by Kokubo (1929). This fact again points to the adjustment of the buffer value and the carbon dioxide tension in the blood of the fresh-water mussels, for the blood gas determinations listed here for fresh-water mussels were made as soon as possible after the animals were removed from the water.

TABLE 9.—*Gas content of fresh-water mussel blood*

Scientific name	Common name	Total gas	Gases in 100 cc. of blood; that is, volumes per cent			
			O_2 plus CO_2	O_2	CO_2	N_2 and other gases
Tritogonia verrucosa	Buckhorn	2.33	1.08	0.71	0.36	1.25
Amblema costata	Three-ridge	2.36	.56			1.80
Do	do	1.86	.78			1.08
Do	do	2.27	.98	.33	.65	1.29
Do	do	2.09	.89	.32	.57	1.21
Andonta limneana	Southern floater	2.23	.72	.36	.36	1.51
Do	do	2.41	1.07	.89	.18	1.34
Lampsilis anodontoides	Yellow sand-shell	2.16	.72			1.44
Do	do	2.61	.99			1.62
Do	do	2.06	.86	.52	.34	1.20
Do	do	1.72	.52	.43	.09	1.20
Do	do	2.26	.89	.24	.65	1.37
Do	do	2.12	.97	.16	.81	1.13
Do	do	1.87	.72	.27	.45	1.15
Do	do	1.95	.80	.27	.53	1.15
Lampsilis siliquoidea pepinensis	Lake Pepin mucket	2.40	1.00			1.40
Actinonais carinata	River mucket	1.91	.32	.18	.14	1.59
Average		2.15	.82	.39	.43	1.34

VERIFICATION OF BLOOD-SALT VALUES BY THE FOOT-STRIPMETHOD

It was observed early in the work that the fresh-water mussel maintains a rather constant and rhythmical motion of the free margin of the muscular foot. When the foot of the mussel is well filled with blood and extruded between the valves of the shell, these movements of the foot are of such magnitude that they are easily visible to the naked eye as undulating waves of contraction pass up and down the foot margin. By attaching a tiny steel hook to the margin of the foot and connecting the foot to a recording lever, by means of this hook and an attached thread a graphic record of these movements of the margin of the foot of the mussel was easily obtained. Placing a small piece of cork between the valves of the mussel when open, and allowing the animal to retract its foot with the tiny hook attached, the valves in closing on the bit of cork were held open far enough to permit the silk thread connecting the hook with the recording lever to move freely and operate the lever. In this way it was possible to study the movements of the foot margin when completely retracted within the shell as well as when expanded. The hook used was so small and light in weight that the animal apparently suffered no inconvenience from the presence of the hook, as mussels were kept under observation for days with the hook in place.

To prevent the mussel from moving away from the connected apparatus, a block of beeswax was first attached to a glass rod and then to one valve of the mussel by melting the surface of the wax and pressing the shell, which had previously been wiped dry with a cloth, into the beeswax just before it hardened. In this way it was possible to suspend the mussel in the water at any desired depth or angle and hold the animal stationary; but at the same time the movements of the foot, gills, and other soft parts were not interfered with in the least, as the mussel could open and close its valves at will. (It may be noted here that this method has proved very satisfactory for several types of experiments and individual mussels have been observed continuously for over three months while attached to beeswax blocks as described.)

From the experiments on the activity of the foot-margin (to be reported in detail elsewhere) it was found that the margin of the foot is kept in constant motion regardless of the position of the foot and whether it be expanded or retracted, and that two rhythms are maintained—that is, there are large contraction waves on which smaller or faster contraction waves are superimposed. These movements of the foot serve not only as part of the locomotion complex, but they produce currents in the water in the vicinity of the foot and in that way aid both respiration and the taking of food.

As these movements continue so regularly and are associated with vital activities of the mussel, they were used to verify the salt concentrations of the blood as determined by the analyses.

It is well established that strips of muscular organs may be removed from the bodies of various animals, and, when mounted properly, these pieces of organs will continue to display normal activity for many hours. As the muscular foot of the fresh-water mussel forms the outer portion of the visceral mass of the animal (see fig. 7) almost the entire foot may be removed by cutting along the line of junction of the foot and viscera. In this way a "foot strip" could be prepared free from all other organs and including almost all of the foot muscle.

Such strips of living tissue from other animals are customarily mounted in the blood serum of the animal from which they were taken or in some fluid containing the principal salts of the blood in the proper proportions, so that strips which have been separated from their connections with the circulatory system may obtain from the fluid in which they are immersed the essential salts or other substances which they would have received from the blood.

In order to test the validity of the normal values which were obtained from the various analyses of mussel blood, such a fluid was compounded containing the principal salts found in mussel blood in the proportions determined by these analyses, and the whole adjusted to the average pH value for mussel blood. This fluid because of its similarity to the "Ringer's fluid" commonly used for studies of vertebrate tissues, was designated "unionid ringers," and the formula is given in the following table:

TABLE 10.—*Composition of unionid ringers fluid in which mussel tissues maintain normal activity*

	Per cent
Sodium chloride	0. 153
Calcium chloride	. 012
Potassium chloride	. 015
Magnesium chloride	. 010
Di-basic sodium phosphate	. 009

Sodium bicarbonate, to adjust the pH value to pH 7.9.

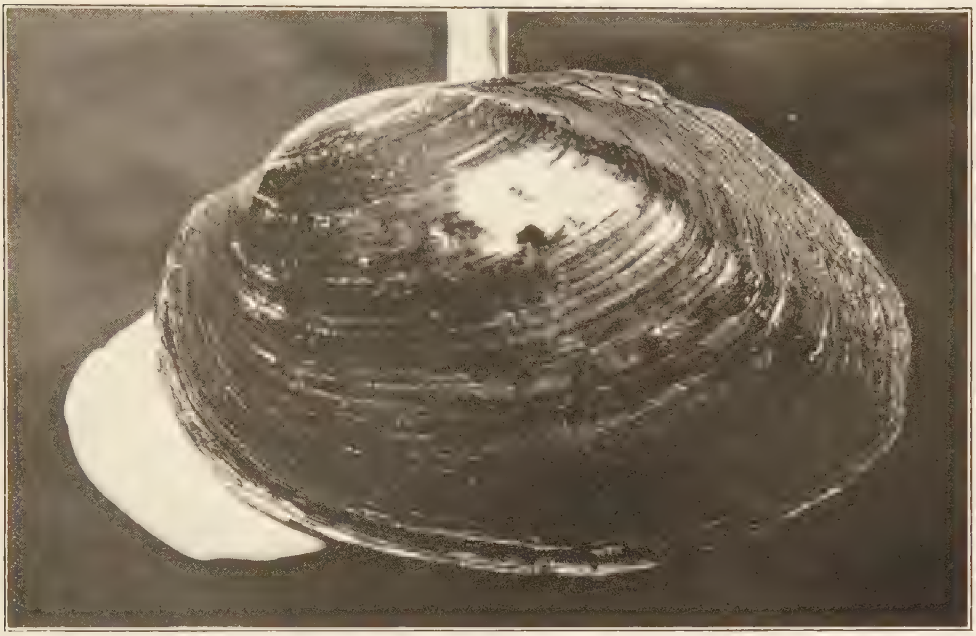

Figure 6.—*Actinonais carinata*, river mucket, natural size. Living animal with foot partly extended

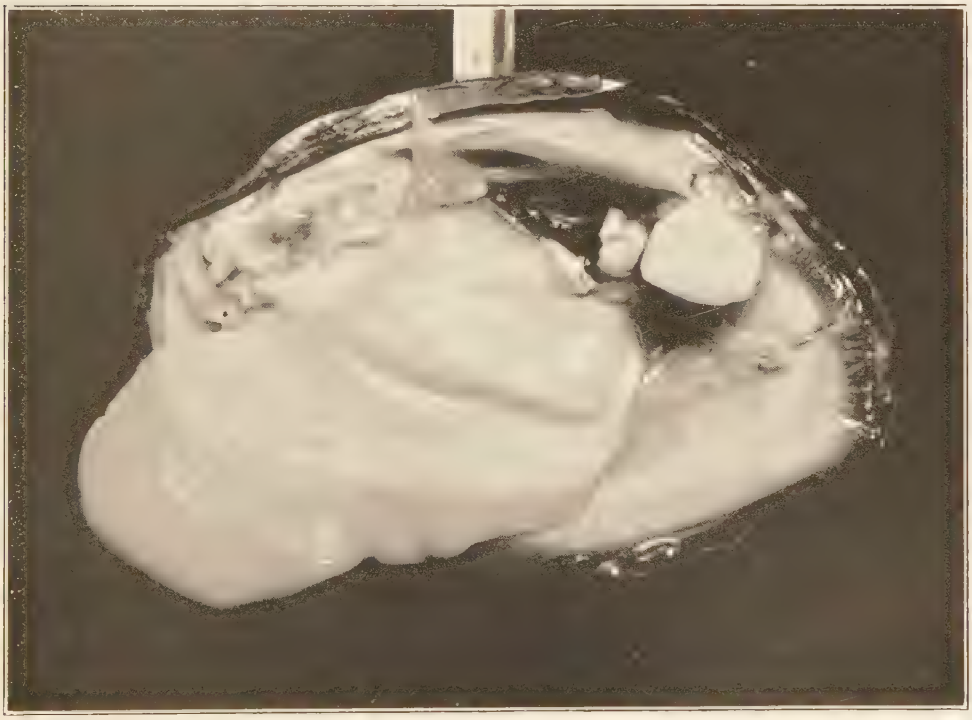

Figure 7.—Living animal (same as Fig. 6) a few minutes later, with one valve of shell removed to show volume of foot. The heart may be seen lying along inside of shell just below hinge. The line of demarcation between foot and visceral mass may be followed as a shallow groove separating the rather rugose foot from the smooth visceral mass. This groove was followed when cutting off the foot strips

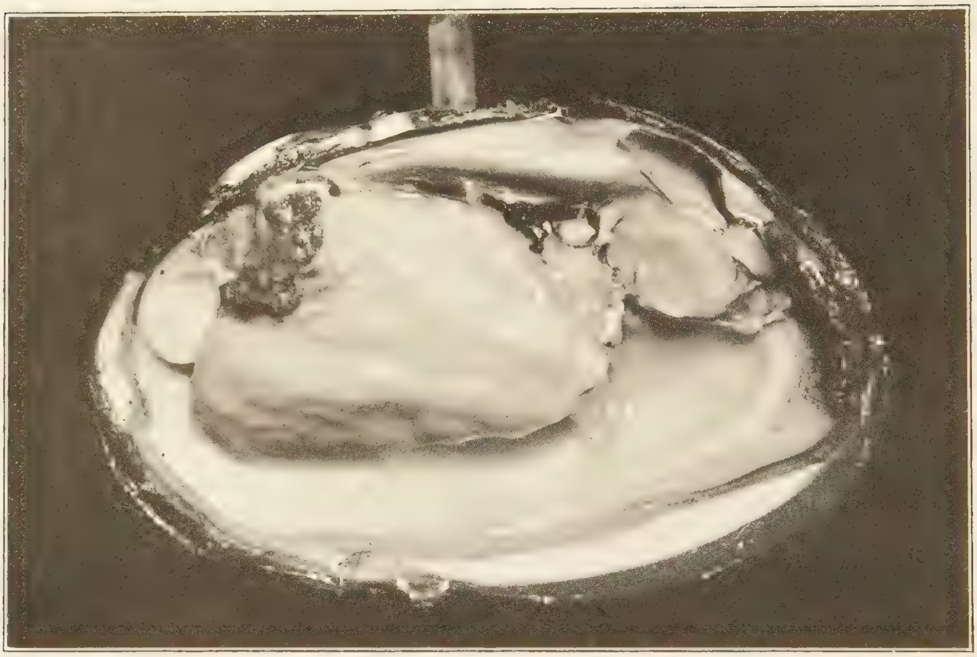

Figure 8. -*Actinonais carinata*, river mucket, natural size. Living animal, with one valve of the shell removed to show foot in a completely retracted condition. Compare volume of foot in this with the expanded foot in preceding figures. The line of demarcation between foot and visceral mass is clearly shown

When foot strips were mounted in glass containers through which well aerated unionid ringers flowed continuously, they maintained the typical rhythmical contractions characteristic of the foot muscle when in place in the body of the mussel. These contractions continued for hours and gave ample opportunity to observe the action of the various blood salts of the mussel blood. (See figs. 5, 6, 7, and 8.)

A summary of these tests will suffice here. The rhythmic activity of the foot strip stopped very quickly when the strip was transferred to distilled water, to tap water, or even river water; that is, the small quantities of salts present in the mussel blood are essential to the activity of the foot tissue. Activity of the foot strips also failed rapidly and finally ceased if the strips were placed in a solution of sodium chloride of the same strength as the sodium chloride in the blood or the unionid ringers, but without the small quantities of potassium, calcium, and magnesium salts found in the mussel blood. It was evident that these other salts, even though present in very small amounts, exercise a regulatory action over the activities of the foot muscle and that sodium chloride alone will not maintain life activities in the mussel. This is similar to the results obtained in experimental studies of other animals. Potassium, calcium, and magnesium salts alone, and in concentrations found the mussel blood, also failed to maintain foot-strip activity. If the balance between calcium and potassium were disturbed—that is, if more or less potassium or calcium were used in proportion to the opposing salt—the activity of the foot strip was quickly disturbed. Excess or unbalanced potassium caused cessation of activity, the strip passing into a condition of rigor; and excess or unbalanced calcium causing cessation of activity accompanied by great loss of tone and relaxation. The limits between which the potassium content of the fluid could be varied were much narrower than those through which calcium variation was tolerated. This is in accord both with the analyses, and with the findings connected with the use of calcium as a buffer by the mussel.

Taken collectively, these tests with the foot strips show that the mussel is dependent upon the salts in the blood for the same types of activity regulation as those found in the higher animals and that although these salts are in very low concentrations in the mussel blood, those concentrations and the balances between the several salts can not be greatly changed without the cessation of activity and other serious consequences. These activity experiments, therefore, validate the analyses of the blood by giving physiological proof that salts are required in the concentrations and proportions determined. As a supplementary check to these tests, the entire heart of the mussel was carefully removed in several cases and mounted in unionid ringers, in which fluid it continued to beat regularly for several hours. Both heart and foot strips were very sensitive to oxygen want and activity ceased almost immediately, no matter what the concentration of the surrounding fluid, if the oxygen supply were shut off.

CHANGES IN BLOOD OF LIVING MUSSELS INDUCED BY ENVIRONMENTAL FACTORS

It was noted repeatedly while collecting the data for the normal values of the mussel blood that the physical factors of the environment influenced to some extent the values obtained. It was necessary, therefore, to select as normals only those animals which had just been removed from the water and which seemed to be in good condition. Nevertheless, even with these precautions, the constituents and characteristics of the mussel blood varied over wider ranges than those for dog or human blood. The fresh-water mussel, however, in a physical sense at least, is in more intimate contact with its environment than many other animals, and the opportunities for the modification of the blood of the mussel are perhaps correspondingly greater.

When the shell of the mussel is open and the foot extruded, the water in which the animal is living has free access to a relatively large surface of soft tissue, and even if the foot be retracted and the shell closed a considerable volume of this same water is retained between the valves within the shell, where this water still bathes the soft parts of the animal. In addition, the mussel pumps through its gill system many times its own volume of water in the course of an active day, and although there is some opportunity to reject suspended objects of unsuitable size or quality at the siphon, because of the innervations of the siphon margins, substances in solution and fine material in suspension have full contact with the large surface of the soft parts and with the delicate structures of the gill system, as long as the animal pumps the water required for respiration and from which it takes its food. The mussel may avoid polluted water temporarily by closing its shell, and preliminary experiments completed by the writers show that these fresh-water mussels can remain closed, at 25° C., for 48 hours or more at a time, if the water included in the shell at the time of closure were well aerated. However, during the period that the mussel is closed it can not move, and therefore it is not able to leave the region of polluted water. Even if the polluted water can be tolerated for a time by the open mussel, the locomotion of the fresh-water mussel is so laborious and slow that the mussel has a much smaller chance of escape than a fish which can swim rapidly to other water. The fresh-water mussel therefore both because of the large amount of soft tissue in contact with the water, and because of its limited locomotion, is particularly exposed to the action of substances in the water.

From the normals obtained for the blood of the fresh-water mussel, the adaptation of these animals to the low osmotic pressure of the fresh-water in which they live is evident by comparison with the blood values of the marine clams—the nearest related forms. In the marine bivalves, the salt balance and adjustments of the blood are in accord with the salt content and the osmotic pressure of the sea water, but when these marine animals are placed in water of higher or lower salt content than that of the sea water in which they normally live (see Kokubo, 1929, on the Japanese oyster), changes in the blood follow shortly, and these changes tend to move the pH, specific gravity, and salt balance toward the level of the new environment, thus tending to equalize the osmotic balance between the animal and its environment.

In view of these observations on marine forms and the known activities of the fresh-water mussels, correlations have been made between the environment, both natural and modified, and the condition of the blood of the fresh-water mussels.

EFFECTS OF CHANGES IN SALT CONTENT OF WATER

To test the effect of changes in the salt content of the water in which the fresh-water mussels were living, both as regards the changes in osmotic pressure and the specific action of the salts themselves, on the blood of the mussels, these animals were placed in glass jars of about 8 liters capacity, containing solutions of various inorganic salts. Fresh-water mussels usually close for a considerable time after being disturbed, particularly if transferred to a new environment, and when they open again the siphons are protruded cautiously so that little of the water in the new location is taken inside of the shell for some time. In order, therefore, that the test solution might have access to the soft parts of the animal at once, the mussels were allowed to close on small bits of cork (as described in the section on foot strips) before the transfer to the test solution. Unless otherwise specified, the valves of all mussels in the following series dealing with the effects of salts were propped open slightly with small pieces of cork.

The solutions used were made up in water from the same source as that supplying the water in which the animals were living, so that they would be subject to no change in salt balance, excepting that change produced by the substance added. The analysis of the water with which the solutions were prepared is given in Table 11.

Table 11.—*Analysis*[2] *of the water in which mussels live at Columbia, Mo.*

	Per cent
Calcium oxide	0. 00832
Magnesium oxide	. 00472
Ferrous oxide	. 00022
Aluminum oxide	. 00001
Silicon dioxide	. 00170
Sulphur (computed as SO_3)	. 00552
Chlorine	. 00194

Each solution jar was constantly aerated by a stream of air bubbles from a compressed-air line, the air passing through water before entering the test solution. The mussels were changed to fresh solution every 24 hours, unless otherwise noted, to avoid the complications resulting from the accumulation of waste products in the solutions. Specific gravity and pH determinations were made regularly on the test solutions themselves as well as on the blood of the mussels in the solutions, to check against unexpected changes in the medium. As the test solutions, with the exception of the distilled-water series, did not show any significant change in either pH or specific gravity values, these determinations for the test solutions have not been included in the tables. Oxygen determinations by the standard Winkler method were also made on the various test solutions to ascertain if the aeration were adequate, and as the oxygen values were all satisfactory they have not been listed.

DISTILLED WATER

For comparison with the responses to the various solutions of salts, several series of mussels were carried in distilled water, but otherwise under the same conditions as the animals in the salt-solution series. The data for these distilled-water tests are given in Table 12 and Figure 9.

Various species of mussels were able to live in aerated distilled water for several days, but all showed a decline in sensitivity, and moribund individuals appeared during the first 24 hours. (Throughout the discussion of these experimental results "moribund" designates a mussel in which the heart had stopped beating when the shell was opened, but the animal was still responsive to tactile stimulation of the mantle margin or the foot.)

It may readily be seen in Figure 9 that the specific gravity of the blood of all mussels living in distilled water was low, as nearly two-thirds of the cases lie below the line of average specific gravity (1.0026) for the blood of fresh-water mussels. This change in specific gravity came quickly, for at the end of the first 48 hours all values were below the average normal. After 96 hours, although still below the average normal specific gravity for mussel blood, the specific gravity of the blood of these individuals in distilled water tended to rise, judging from the few observations beyond 96 hours. This rise in specific gravity is suggestive in connection with the pH values of the blood.

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[2] Figures from analyses made by department of physical chemistry, University of Missouri.

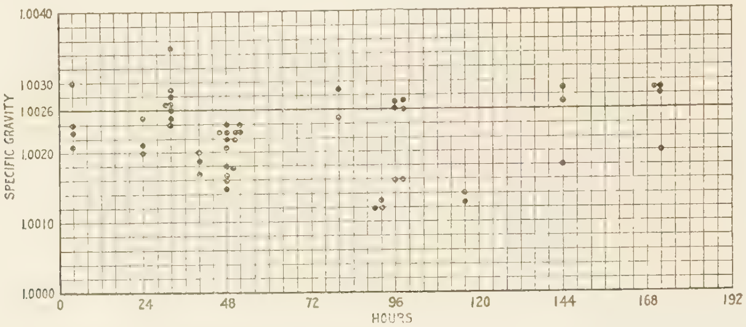

FIGURE 9.—Specific gravity of the blood of fresh-water mussels in distilled water

TABLE 12.—*Changes in specific gravity and pH of the blood of fresh-water mussels in distilled water*

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Quadrula trapezoides	Washboard	4	Heart beating	7.7	1.0021
Do	do	4	do	7.7	1.0023
Do	do	4	do	7.7	1.0024
Do	do	4	do	7.7	1.0030
Do	do	24	Moribund	8.1	1.0020
Do	do	24	Heart beating	8.3	1.0021
Do	do	24	Moribund	7.9	1.0025
Do	do	32	do	7.6	1.0024
Do	do	32	Heart beating	7.7	1.0025
Do	do	32	Moribund	7.6	1.0026
Do	do	32	Heart beating	7.7	1.0027
Do	do	32	Moribund	7.7	1.0027
Do	do	32	do	7.5	1.0028
Do	do	32	Heart beating	7.7	1.0029
Do	do	32	do	7.7	1.0035
Actinonais carinata	River mucket	40	do	8.1	1.0017
Do	do	40	do	8.0	1.0019
Do	do	40	do	8.0	1.0020
Quadrula trapezoides	Washboard	48	do	7.6	1.0015
Do	do	48	do	7.3	1.0016
Do	do	48	Moribund	7.6	1.0017
Do	do	48	Heart beating	8.0	1.0018
Do	do	48	do	7.4	1.0021
Do	do	48	do	7.9	1.0022
Do	do	48	do	7.9	1.0023
Do	do	48	Moribund	7.3	1.0024
Do	do	52	Heart beating	7.7	1.0023
Do	do	52	do	7.9	1.0023
Do	do	52	do	7.9	1.0024
Do	do	76	do	8.1	1.0025
Do	do	76	Moribund	8.2	1.0029
Actinonais carinata	River mucket	92	Heart beating	7.6	1.0012
Do	do	92	do	7.7	1.0012
Do	do	92	do	7.6	1.0013
Quadrula trapezoides	Washboard	96	do	7.5	1.0016
Do	do	96	do	7.5	1.0026
Do	do	96	do	7.5	1.0027
Unio popeii	Pope's purple	96	do	7.5	1.0026
Do	do	96	do	7.5	1.0027
Proptera laevissima	Paper shell	96	do	7.5	1.0016
Quadrula trapezoides	Washboard	116	Moribund	7.8	1.0013
Do	do	116	Heart beating	8.1	1.0014
Unio popeii	Pope's purple	144	do	7.5	1.0027
Do	do	144	do	7.5	1.0029
Proptera laevissima	Paper shell	144	do	7.7	1.0018
Anodonta limneana	Southern floater	172	Dead	7.1	1.0020
Unio popeii	Pope's purple	172	Heart beating	8.4	1.0028
Do	do	172	do	8.3	1.0029

NOTE.—"Moribund," under condition of animal, designates a mussel in which the heart was not beating when shell was opened but an animal still responding to tactile stimulation of the foot or mantle.

In Figure 4 a relation between the specific gravity and the pH of the blood of fresh-water mussels was pointed out; namely, that as the blood approached neutrality the specific gravity rose—that is, the more alkaline bloods were usually those with the lower specific gravities. Under both the discussion of blood salts and of blood gases it was also noted that during exposures to conditions causing retention of carbon dioxide in the body of the mussel, the animal made more or less compensation by buffering down the carbon dioxide with calcium carbonate withdrawn from the shell. This addition of calcium salts to the blood, of course, affects the specific gravity of that fluid, not only through the actual addition of calcium salts and the retention of carbonates in the blood but also through the effects on various other constituents of the blood.

Throughout the several series of experimental tests, both with salts and with exposures to air, it was observed that as the mussel became moribund the specific gravity of the blood usually rose, and with this rise in specific gravity the pH value of the same blood approached neutrality; that is, became less alkaline. In animals which had been moribund or dead for several hours (but before decomposition changes set in) the blood frequently became quite alkaline again. This sequence of specific gravity and pH changes in the blood of living mussels and those which had just died was interpretated as showing the buffering action of the calcium carbonate of the shell on the acid products which are known to form in the tissues of moribund animals. It is also possible that changes in permeability develop under these conditions.

Applying these observations to the distilled water cases, the specific gravity of the blood of these mussels might be expected to rise slightly as the animal became moribund from the effects of the distilled water, but was still tending to buffer down the accumulating acid products.

Three checks were made. Mussels were placed in distilled water pH 5.3, and they were found to die more rapidly than mussels in the same distilled water adjusted to pH 6.8, particularly if the acid distilled water were changed frequently. If mussels were placed in distilled water pH 5.3 the pH of the water rose to pH 6.8 in 24 hours whereas control jars without mussels showed no change in pH. In order to evaluate this change in pH in the water around the mussels, fresh, empty mussel shells from which the living animals had just been removed were wiped dry and the inner surfaces completely coated with paraffin; that is only those parts of the shell which would be in contact with the water, were the shell occupied by the living mussel, were left uncoated with paraffin. The paraffined shells were then placed in acid distilled water pH 5.3 and treated as if the shells contained living mussels. After about 30 hours the pH of the water around these paraffined shells had risen to pH 6.8, where it remained. In the third check, mussels were placed in distilled water pH 5.3 and no change of fluid made, but the usual aeration was maintained. After 24 hours the water around these mussels had a pH of 6.8 and 24 hours later it had risen to pH 7.3. The blood of these mussels was near but still below average normal at the end of 144 hours. The distilled water even under these conditions continued to be toxic, and the animals died after about 200 hours.

Considering all of the distilled water data collectively the fresh-water mussels were found to be very sensitive to the hypotonic and unbuffered conditions of the environment offered by distilled water, in spite of the fact that the blood of the fresh-water mussels is much more dilute than that of the higher animals, and the corresponding difference in tonicity between the blood and the fluid surrounding the animal much less. The specific gravity of the blood was definitely reduced during the first 24 hours of exposure to distilled water and remained low throughout the tests (nearly 200 hours in some cases). The rapidity of these changes in specific gravity of the blood suggests that the osmotic barrier between the blood of the fresh-water mussels and the fluid of their environment is not great, the fluid of the body tending to come to equilibrium with the environment rather promptly. The pH value of the blood was maintained fairly well as long as the animal was reasonably active, but the alkalinity of the blood fell as the mussel became moribund or as the exposure to distilled water lengthened.

SODIUM SALTS

As the fresh-water mussels are supposed to have evolved from marine clams and as sodium chloride is the major inorganic salt found in all living animals, sodium chloride was chosen as the standard with which to compare the action of the various hypertonic solutions used. Besides, as this salt passes through animal membranes easily under most conditions, the toxic action of sodium chloride to living tissues, in concentrations greater than the so-called physiological solutions, is well known.

Three solutions of sodium chloride were used in the tests on fresh-water mussels: A 0.25 per cent solution, which is roughly isotonic with the blood of fresh-water mussels; a 0.50 per cent solution, comparable with the blood of most cold-blooded vertebrates, and that of many invertebrates; and a 1.00 per cent solution, which is slightly more concentrated than mammalian or avian blood. The data from these series of tests are presented in Table 13 and Figure 10.

TABLE 13.—*Changes in specific gravity and pH of the blood of fresh-water mussels in solutions of sodium salts.*

SODIUM CHLORIDE, 1.00 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Quadrula trapezoides	Washboard	4	Heart beating	8.0	1.0046
Do	do	4	do	7.3	1.0051
Do	do	4	do	7.6	1.0051
Do	do	4	do	7.6	1.0051
Do	do	12	do	7.4	1.0056
Do	do	12	do	7.4	1.0072
Do	do	12	do	7.5	1.0073
Do	do	24	do	7.0	1.0053
SODIUM CHLORIDE, 0.50 PER CENT					
Quadrula trapezoides	Washboard	4	Heart beating	7.9	1.0033
Do	do	4	do	7.8	1.0036
Do	do	4	do	7.8	
Do	do	12	do	7.5	1.0054
Do	do	12	do	7.8	1.0054
Do	do	12	do	7.8	1.0059
Do	do	24	Moribund	7.0	1.0049
Do	do	24	do	7.0	1.0050
Do	do	24	Heart beating	7.0	1.0050
Do	do	24	do	7.5	1.0056
SODIUM CHLORIDE, 0.25 PER CENT					
Quadrula trapezoides	Washboard	4	Heart beating	8.0	1.0029
Do	do	4	do	8.1	1.0036
Do	do	24	do	7.2	1.0030
Do	do	24	do	7.9	1.0030
Do	do	24	do	7.9	1.0032
Do	do	24	do	8.0	1.0041
Do	do	76	do	7.7	1.0034
Do	do	76	do	7.9	1.0034
Do	do	76	do	7.9	1.0036
Do	do	76	do	7.7	1.0037

NOTE.—"Moribund," under condition of animal, designates a mussel in which the heart was not beating when shell was opened, but an animal still responding to tactile stimulation of the foot or mantle.

The almost immediate rise in specific gravity of the blood of fresh-water mussels when placed in these solutions of sodium chloride is in sharp contrast with the results of the distilled water series, and confirms the statement made in the discussion of the distilled water series that the restriction to osmotic adjustment between the blood of the fresh-water mussel and its fluid environment is slight. Within four hours after placing the mussels in these salt solutions the specific gravity of the blood of all individuals exceeded the average normal specific gravity for the blood of fresh-water mussels excepting one. This mussel (see fig. 10) was placed in 0.50 per cent sodium chloride solution while closed, and without a cork between the valves. It is probable that very little of the salt solution penetrated to the soft parts of this animal as it was not observed to open its valves during this 4-hour period. Several other mussels were tested in the salt solutions in this same way; that is, they were closed in air and then placed in the solution while closed without cork between the valves. The data from these animals have been included in Figure 10 (not in Table 13) for comparison. For the most part these closed animals remained closed in the salt solutions and took little of the test solutions inside their shells, as the blood specific gravities attest.

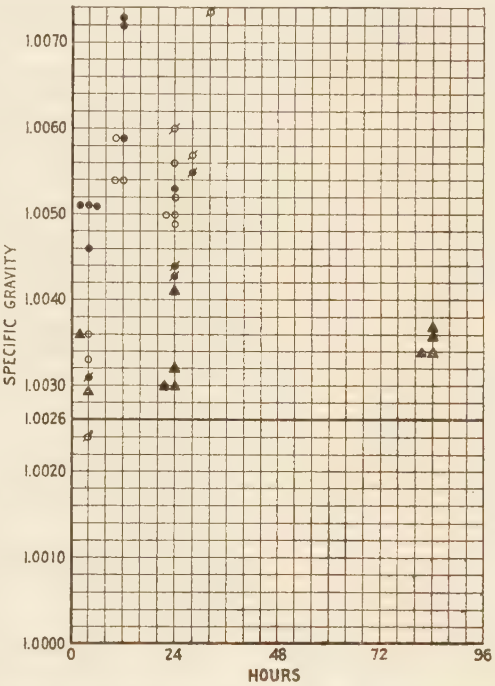

Figure 10.—Specific gravity of the blood of fresh-water mussels in tap water plus sodium chloride. Black circle, 1 per cent sodium chloride, valves propped open; scored black circle, 1 per cent sodium chloride, animal unrestricted; circle, 0.5 per cent sodium chloride, valves propped open; scored circle, 0.5 per cent sodium chloride, animal unrestricted; black triangle, 0.25 per cent sodium chloride, valves propped open

By graded additions of salt to the water in which European fresh-water mussels (Anodonta and Unio) were living, Beudant (1816), found that these animals could adapt themselves to almost 2 per cent salt solution. Similarly, Philippson, Hannevart, and Thieren (1910) were able to raise the salt content of the water in which specimens of the European fresh-water mussel, *Anodonta cygnea*, were living to 2 per cent if sodium chloride were used, or even higher if "sea salt" were added gradually. In this work they found, using the electroconductivity method, that the salt content of the blood of these fresh-water mussels rose, but that the salt value of the blood never equaled the salt content of the surrounding medium, presumably because of the presence of some colloidal material in the mussel blood. The return of salt-adapted mussels to fresh water was also followed by a drop in the salt content of the mussel blood as these animals readapted themselves to the fresh water. These observations on the European fresh-water mussel parallel the findings in the present series of North American fresh-water mussels.

The degree of adaptation which North American fresh-water mussels can make to solutions of sodium chloride, following the gradual addition of this compound to the water in which these mussels are found, is not to be discussed here; but the rapid changes in specific gravity of the blood of these mussels following abrupt changes from fresh water to even dilute salt solutions show the potential dangers to the fresh-water mussels from the addition of salt to the water in which they are living, which may result from the introduction of certain types of industrial wastes.

The pH values of the blood of mussels from the sodium chloride series seemed to vary toward neutrality, the greater the concentration of the salt solution. This finding, in view of observations made in other series, suggests that the stronger solutions, as might be expected, were producing more extended disturbances of the body functions than the weaker solutions.

POTASSIUM SALTS

Various species of mussels were tested in solutions of potassium chloride, potassium carbonate, potassium sulphate, and in a mixture of potassium chloride and calcium chloride. These series are summarized in Table 14 and Figure 11.

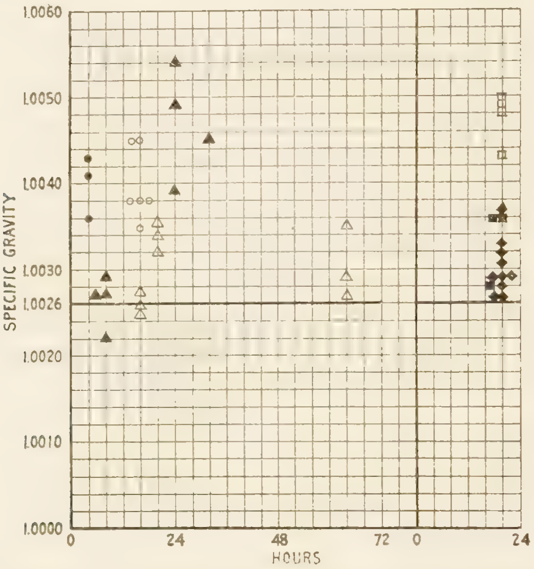

Figure 11.—Specific gravity of the blood of fresh-water mussels in tap water plus potassium salts. All animals with valves propped open. Black circle, 1 per cent potassium chloride; circle, 0.50 per cent potassium chloride; black triangle, 0.25 per cent potassium chloride; triangle, 0.10 per cent potassium chloride; square, 0.5 per cent carbonate; black square 0.25 per cent potassium carbonate; and black triangle, 0.25 per cent potassium sulphate

The toxic action of the potassium salts on fresh-water mussels is evident from these tests, and is in accord with the known toxic action of potassium compounds to other types of animals. The mussels rapidly became moribund in solutions of potassium salts, and as a result the potassium series were not carried beyond 24 hours in most cases.

The general effects of potassium salts on the specific gravity of the blood were the same as those noted for the sodium chloride series. The animals made rapid adjustments in the specific gravity of the blood, the actual values being well above the average normal specific gravity of fresh-water mussel blood.

Owing to the high toxicity of the potassium salts, the body condition declined rapidly and the alkalinity of the blood was lowered, as in other moribund mussels. Extreme retraction of the foot was evident in mussels dying in solutions of potassium salts.

TABLE 14.—*Changes in specific gravity and pH of the blood of fresh-water mussels in solutions of potassium salts*

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
POTASSIUM CHLORIDE 1.00 PER CENT					
Quadrula trapezoides	Washboard	4	Heart beating	7.9	1.0036
Do	do	4	Moribund	7.9	1.0041
Do	do	4	do	7.5	1.0043
POTASSIUM CHLORIDE, 0.50 PER CENT					
Quadrula trapezoides	Washboard	16	Moribund	7.5	1.0035
Do	do	16	do	7.5	1.0038
Do	do	16	do	7.5	1.0038
Do	do	16	do	7.7	1.0038
Do	do	16	do	7.5	1.0045
Do	do	16	Dead		1.0045
POTASSIUM CHLORIDE, 0.25 PER CENT					
Lampsilis anodontoides	Yellow sand-shell	8	Moribund	7.5	1.0022
Do	do	8	do	7.5	1.0027
Do	do	8	Heart beating	7.5	1.0027
Do	do	8	Moribund	7.5	1.0029
Do	do	24	Dead		
Do	do	24	Heart beating	7.3	1.0039
Do	do	24	do	7.3	1.0049
Do	do	24	do	7.5	1.0054
Do	do	32	Moribund	7.4	1.0045
POTASSIUM CHLORIDE, 0.10 PER CENT					
Lampsilis anodontoides	Yellow sand-shell	16	Moribund	7.7	1.0025
Do	do	16	do	7.5	1.0026
Do	do	16	do	7.3	1.0027
Quadrula nodulata	Warty-back	16	do	7.1	1.0027
Lampsilis anodontoides	Yellow sand-shell	20	do	6.9	1.0032
Proptera laevissima	Paper shell	20	Heart beating	7.3	1.0034
Quadrula nodulata	Warty-back	20	do	7.1	1.0035
Actinonais carinata	River mucket	64	Moribund	7.1	1.0027
Proptera laevissima	Paper shell	64	do	7.3	1.0029
Quadrula nodulata	Warty-back	64	do	7.3	1.0035
POTASSIUM CARBONATE, 0.50 PER CENT					
Unio popeii	Pope's purple	20	Moribund	7.1	1.0043
Do	do	20	Dead	7.1	1.0048
Do	do	20	Moribund	7.3	1.0050
Anodonta imbecillis	Pond paper shell	20	do	7.2	1.0049
POTASSIUM CARBONATE, 0.25 PER CENT					
Quadrula trapezoides	Washboard	20	Moribund	7.5	1.0028
Do	do	20	do	7.7	1.0035
Do	do	20	Dead	8.0	1.0035
POTASSIUM SULPHATE, 0.25 PER CENT					
Quadrula trapezoides	Washboard	20	Moribund	8.0	1.0027
Do	do	20	do	7.7	1.0028
Do	do	20	do	7.5	1.0029
Do	do	20	do	7.5	1.0029
Do	do	20	do	7.6	1.0031
Do	do	20	do	7.6	1.0032
Do	do	20	do	7.3	1.0033
Do	do	20	Dead	7.6	1.0027
Do	do	20	do	7.5	1.0029
Do	do	20	do	7.3	1.0037
POTASSIUM CHLORIDE, 0.25 PER CENT; PLUS CALCIUM CHLORIDE, 0.25 PER CENT [1]					
Actinonais carinata	River mucket	4	Heart beating	7.5	1.0030
Do	do	4	do	8.0	1.0030
Do	do	4	do	7.5	1.0035
Lampsilis siliquoidea	Fat mucket	24	Moribund	7.3	1.0041
Do	do	24	Heart beating	7.5	1.0042
Actinonais carinata	River mucket	24	Moribund	7.3	1.0042
Do	do	24	do	7.5	1.0043
Do	do	24	do	7.3	1.0043

[1] Made up in distilled water.

NOTE.—"Moribund," under condition of animal, designates a mussel in which the heart was not beating when shell was opened but an animal still responding to tactile stimulation of the foot or mantle.

MAGNESIUM SALTS

The rôle of magnesium salts in the blood of animals is not so well understood as that of some of the other salts, but as magnesium compounds occur in the blood of fresh-water mussels and also in the water (often in relatively large amounts), in which these animals live, a series of mussels were tested in solutions of magnesium salts. The data for these series are given in Table 15 and Figure 12.

As far as determined by these series, the adjustment to magnesium salts, if they be present in amounts which can be tolerated, is made rather quickly. Mussels transferred to 1.00 per cent solution of magnesium sulphate showed the same rather abrupt rise in specific gravity of the blood during the first 24 hours as that noted for the salts of sodium and potassium, and 0.50 per cent solutions of magnesium sulphate and magnesium chloride produced lesser elevations of the blood specific gravity. Beyond the first 24 hours, the results suggest a return to normal blood specific gravity or below, although the data are scant. From the reactions of the mussels to the various solutions of magnesium salts used, the toxicity of magnesium compounds seems much less than that of either potassium or sodium salts, but it must be remembered in this connection that the permeability of living cells to magnesium salts is quite different from that to either potassium or sodium salts.

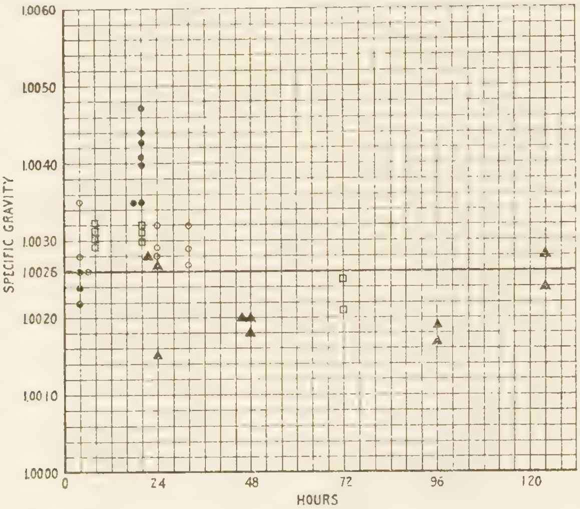

FIGURE 12.—Specific gravity of the blood of fresh-water mussels in tap water plus magnesium salts. All animals with valves propped open. Black circle, 1 per cent magnesium sulphate; circle 0.5 per cent magnesium sulphate; black triangle, 0.25 per cent magnesium sulphate; and square 0.5 per cent magnesium chloride

TABLE 15.—*Changes in specific gravity and pH of the blood of fresh-water mussels in solutions of magnesium salts*

MAGNESIUM SULPHATE, 1.00 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Quadrula trapezoides	Washboard	4	Heart beating	7.7	1.0022
Do	do	4	do	8.1	1.0024
Do	do	4	do	8.1	1.0026
Fusconaia ebena	Niggerhead	20	do	7.2	1.0035
Do	do	20	do	7.7	1.0035
Do	do	20	do	7.7	1.0041
Megalonaias gigantea	Washboard	20	Moribund	8.1	1.0044
Do	do	20	Heart beating	7.9	1.0047
Quadrula trapezoides	do	20	do	7.5	1.0040
Do	do	20	do	7.5	1.0043

MAGNESIUM SULPHATE, 0.50 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Megalonaias gigantea	Washboard	4	Heart beating	8.0	1.0026
Do	do	4	Moribund	8.1	1.0028
Do	do	4	Heart beating	7.7	1.0035
Do	do	24	Moribund	7.7	1.0028
Do	do	24	Heart beating	8.1	1.0029
Do	do	24	Moribund	8.0	1.0032
Do	do	28	Heart beating	7.7	1.0027
Do	do	28	do	7.7	1.0029
Lampsilis anodontoides	Yellow sand-shell	28	Moribund	7.7	1.0032

MAGNESIUM SULPHATE, 0.25 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Plagiola lineolata	Butterfly	24	Heart beating	8.1	1.0028
Megalonaias gigantea	Washboard	24	do	8.1	1.0027
Fusconaia undata	Pig toe	24	do	8.0	1.0015
Megalonaias gigantea	Washboard	48	do	8.1	1.0018
Do	do	48	do	8.1	1.0020
Do	do	48	Moribund	8.1	1.0020
Do	do	96	Heart beating	8.1	1.0017
Plagiola lineolata	Butterfly	96	do	8.1	1.0019
Quadrula trapezoides	Washboard	124	do	8.5	1.0024
Unio popeii	Pope's purple	124	do	7.9	1.0028

MAGNESIUM CHLORIDE, 0.50 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Lampsilis siliquoides	Fat mucket	8	Heart beating	7.9	1.0029
Do	do	8	do	7.8	1.0030
Do	do	8	do	7.9	1.0031
Do	do	8	do	8.0	1.0032
Do	do	20	do	8.0	1.0030
Do	do	20	do	7.8	1.0032
Actinonais carinata	River mucket	20	Dead	8.1	1.0031
Do	do	72	Heart beating	8.1	1.0021
Do	do	72	do	7.7	1.0025

NOTE.—"Moribund," under condition of animal, designates a mussel in which the heart was not beating when shell was opened, but an animal still responding to tactile stimulation of the foot or mantle.

CALCIUM SALTS

As calcium salts play such an important part in the life activities of the fresh-water mussels, even to limiting the distribution of these animals very largely to regions where calcium salts are readily available in the water, calcium salts have been made the basis of a more detailed series of studies, which are only summarized in part here. In Table 16 and Figure 13 individual data for a series of calcium tests are presented. These will suffice to show the main points in relation to the blood.

The responses of the mussels living in calcium-salt solutions were very quickly adjusted, so that if the solutions were not too strong the mussels behaved much as in ordinary fresh water. The specific gravity of the blood of animals transferred to the stronger solutions rose during the first 24 to 48 hours, after which the readings range about the normal blood specific gravity. Four high cases (see fig. 13), one at

192 hours, one at 168 hours, and two at 144 hours, seem to be exceptions to this statement in the series given. These animals present an interesting complication as all were moribund. Moribund animals in calcium solutions displayed the same rise in blood specific gravity and loss of blood alkalinity as moribund individuals in any other series. This suggests that the buffering of acid products in the body of the mussel draws on calcium in the body rather than that in the environment.

TABLE 16.—*Specific gravity and pH of the blood of fresh-water mussels in solutions of calcium salts*

CALCIUM CHLORIDE, 1.00 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Lampsilis anodontoides	Yellow sand-shell	24	Dead		
Do	do	24	do		
Do	do	24	do		
Do	do	24	Heart beating	7.5	1.0038
Do	do	24	do	7.3	1.0055
Amblema costata	Three-ridge	24	Dead		

CALCIUM CHLORIDE, 0.50 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Anodonta limneana	Southern floater	24	Heart beating	7.5	1.0037
Do	do	48	do	8.1	1.0032
Do	do	48	Dead		
Lampsilis anodontoides	Yellow sand-shell	72	Heart beating	7.6	1.0027
Do	do	96	do	7.3	1.0029
Amblema costata	Three-ridge	168	Moribund	7.0	1.0045
Lampsilis anodontoides	Yellow sand-shell	192	Heart beating	7.6	1.0032
Do	do	216	do	7.3	1.0031
Do	do	244	do	7.7	1.0033
Do	do	268	do	7.4	1.0034

CALCIUM CHLORIDE, 0.25 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Lampsilis anodontoides	Yellow sand-shell	24	Heart beating	7.7	1.0026
Do	do	24	do		1.0043
Do	do	48	do	8.0	1.0030
Do	do	48	do	7.9	1.0042
Do	do	48	do	7.6	1.0054
Do	do	72	do	7.4	1.0026
Amblema costata	Three-ridge	96	do	7.9	1.0022
Lampsilis anodontoides	Yellow sand-shell	120	Dead		
Do	do	120	Heart beating	7.8	1.0037
Do	do	144	Moribund	7.6	1.0039
Do	do	144	do	7.6	1.0043
Do	do	168	Heart beating	8.0	1.0029
Do	do	192	do	7.5	1.0025
Do	do	192	Moribund	7.1	1.0047
Do	do	216	Heart beating	8.1	1.0017
Do	do	244	do	8.1	1.0011
Do	do	244	do	8.1	1.0021
Do	do	268	do	8.2	1.0023
Do	do	268	do	8.2	1.0030
Do	do	268	do	8.0	1.0033
Lampsilis fallaciosa	Slough sand-shell	408	do	8.1	1.0017
Obliquaria reflexa	Three-horned warty-back	408	do	7.9	1.0022
Tritogonia verrucosa	Buckhorn	408	do	7.4	1.0027

CALCIUM CHLORIDE, 0.10 PER CENT

Scientific name	Common name	Hours of exposure	Condition of animal	pH	Specific gravity
Lampsilis fallaciosa	Slough sand-shell	72	Heart beating	7.8	1.0033
Tritogonia verrucosa	Buckhorn	96	do	7.7	1.0024
Lampsilis fallaciosa	Slough sand-shell	412	do	7.8	1.0013

The calcium salt solutions were conspicuously less toxic than any of the other groups of salts studied, judging by the survivals and by the small number of moribund individuals found. In connection with the toxic action of the calcium salts it must be stated, however, that these observations on adult mussels do not apply to the glochidia. Adult females were found to tolerate solutions of calcium salts which greatly lengthened the closing reaction time of the glochidia which these same mussels were carrying in their marsupia. In some cases glochidia, from the marsupia of mussels which had been carried successfully for several days in solutions of calcium salts, were so reduced in sensitivity that 10 per cent sodium chloride solution was required to excite these glochidia to the closing response, although the glochidia appeared otherwise to be in splendid condition.

Blood sugar and blood ash determinations were made on the blood of mussels from both the calcium-salt series and the sodium-salt series. In both groups the blood sugar was found to vary within the same limits as those defined for the normal animals, but the blood ash in both sodium and calcium series was higher than in normal mussels. The increase in blood ash shows that in the calcium and sodium series the mussels during the period of high-blood specific gravity, actually had more inorganic solids in their blood. Whether this rise in ash content was due to the loss of water from the blood, thereby producing a concentration of the salts already in the blood, or whether this high ash content represented a movement of salts into the blood, was not determined. In either event, however, the tissues of the animal were subjected to a blood of higher salt concentration.

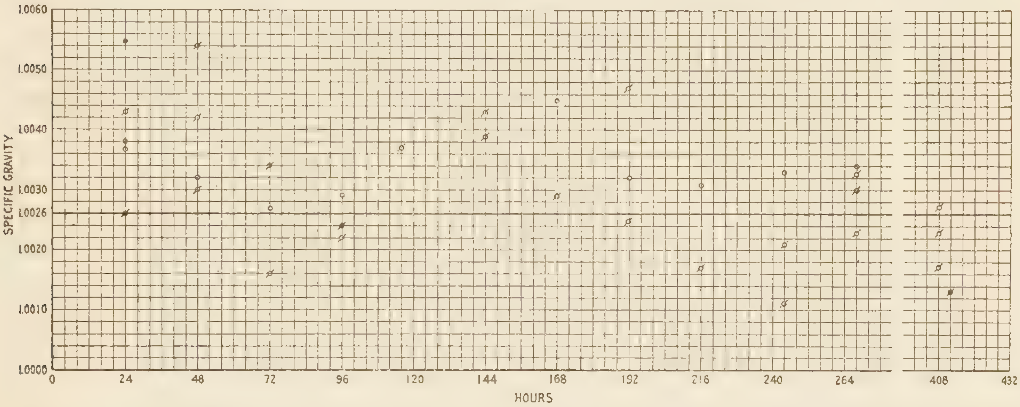

FIGURE 13.—Blood specific gravity of mussels living in solutions of calcium salts. Black circle, 1 per cent calcium chloride; circle, 0.5 per cent calcium chloride; scored circle, 0.25 per cent calcium chloride; scored black circle, 0.1 per cent calcium chloride

EFFECTS OF EXPOSURES TO AIR

AT ORDINARY TEMPERATURES

Sudden changes in stream level may leave fresh-water mussels stranded out of water, but ordinarily the low-water stages come so slowly that littoral forms like the slough sand-shell, *Lampsilis fallaciosa,* and species which move in and out of shallow water as the yellow sand-shell, *Lampsilis anodontoides,* may easily keep ahead of the receding water. For mussel species living on bars in deeper water, exposure to the air is a more or less remote possibility in their normal-life activities.

The work attendant on propagation of mussels has made it necessary to expose mussels to the air, and often these animals are shipped long distances without water. To determine the effect of removal from water and exposure to air on the mussel, using the blood as an index, a series of 50 mussels was taken directly from the river to the laboratory, wiped dry and spread out separately so that there could be no accumulation of water below or around the mussels. Every opportunity was offered, therefore, for these mussels to "dry out" at room temperature.

Blood samples were taken at intervals and only those mussels which were closed at the time the sample was to be taken were used. The determinations of specific gravity for the blood from the 28 individuals which survived this treatment are given in Table 17 and Figure 14.

During the first four hours of exposure to air the rise in blood specific gravity became evident. This may have resulted from either the loss of water from the blood, or from the addition of calcium salts to the blood to buffer down the products of respiration in the animal now deprived of its regular supply of fresh water; or both factors may have contributed to the rise in specific gravity.

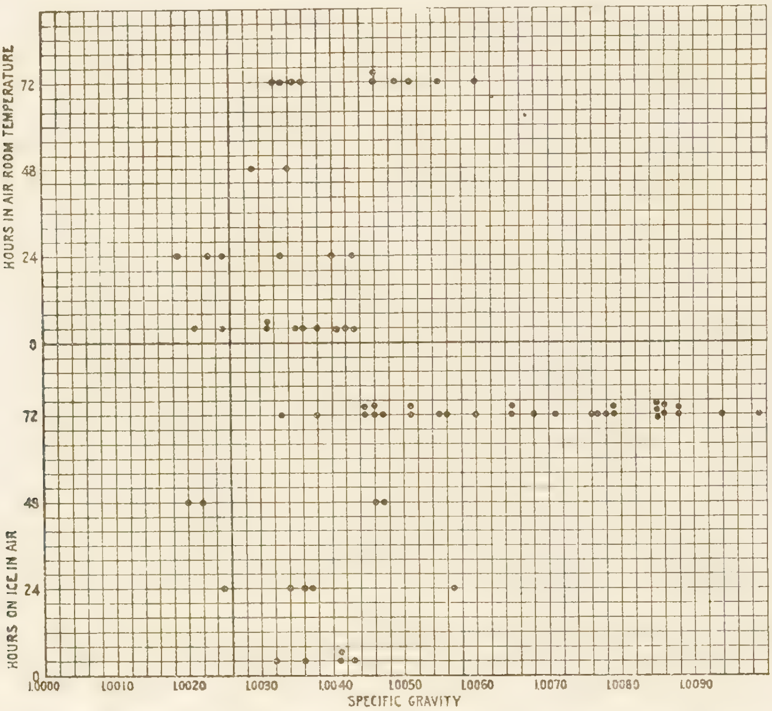

FIGURE 14.—Blood specific gravity of mussels exposed to air. Upper half, in air at room temperature; lower half, in air on ice

The specific gravity of the blood continued to rise throughout the test. It was noted that those mussels which remained closed survived, while those which opened the valves and thereby lost some or all of the water which had been retained between the valves when the animal closed, as it was being taken from the river, soon succumbed.

The pH value of the blood remained near pH 7.7 in most of the animals from which samples were taken, but all moribund animals were rejected in this series.

TABLE 17.—*Specific gravity and pH values for the blood of fresh-water mussels exposed to the air*

IN AIR AT ROOM TEMPERATURE, 24°

Scientific name	Common name	Hours of exposure	Specific gravity	pH
Tritogonia verrucosa	Buckhorn	4	1.0037	7.7
Do	do	24	1.0043	7.9
Fusconaia ebena	Niggerhead	72	1.0036	7.7
Do	do	72	1.0033	7.9
Do	do	72	1.0060	7.8
Do	do	72	1.0055	7.7
Do	do	72	1.0035	7.8
Fusconaia undata	Pig toe	4	1.0042	7.9
Do	do	4	1.0031	7.7
Do	do	24	1.0033	7.8
Do	do	72	1.0049	8.0
Do	do	72	1.0046	7.9
Amblema costata	Three-ridge	4	1.0021	7.7
Do	do	4	1.0031	7.8
Do	do	24	1.0019	7.5
Do	do	48	1.0029	7.7
Do	do	48	1.0034	7.7
Do	do	72	1.0046	7.5
Amblema rariplicata	Blue point	72	1.0032	7.9
Quadrula pustulosa	Pimple back	4	1.0036	7.7
Do	do	4	1.0043	7.7
Do	do	24	1.0040	7.6
Quadrula metanevra	Monkey face	4	1.0035	7.8
Megalonaias gigantea	Washboard	4	1.0041	7.6
Strophitus rugosus	Squaw foot	24	1.0025	7.7
Actinonais carinata	River mucket	4	1.0025	7.7
Do	do	24	1.0023	7.7
Lampsilis higginsii	Higgins eye	72	1.0051	7.7
IN AIR, ON ICE				
Fusconaia ebena	Niggerhead	24	1.0057	7.7
Do	do	72	1.0065	7.6
Do	do	72	1.0076	7.5
Fusconaia undata	Pig toe	4	1.0043	7.6
Do	do	24	1.0037	7.5
Do	do	48	1.0047	7.6
Do	do	72	1.0056	7.7
Do	do	72	1.0077	7.7
Do	do	72	1.0079	7.7
Amblema costata	Three-ridge	4	1.0041	7.6
Do	do	24	1.0036	7.6
Do	do	48	1.0046	7.5
Do	do	72	1.0035	7.7
Amblema rariplicata	Blue point	72	1.0055	7.7
Quadrula pustulosa	Pimple back	4	1.0032	7.8
Do	do	24	1.0034	7.6
Do	do	48	1.0022	7.4
Do	do	72	1.0045	7.6
Do	do	72	1.0046	7.6
Do	do	72	1.0068	7.6
Do	do	72	1.0085	7.6
Do	do	72	1.0086	7.8
Do	do	72	1.0088	7.6
Quadrula metanevra	Monkey face	72	1.0038	7.7
Do	do	72	1.0051	7.7
Do	do	72	1.0051	7.7
Do	do	72	1.0060	7.6
Do	do	72	1.0078	7.7
Do	do	72	1.0085	7.7
Do	do	72	1.0086	7.5
Do	do	72	1.0089	7.5
Do	do	72	1.0099	7.8
Quadrula nodulata	Warty-back	72	1.0047	7.7
Do	do	72	1.0071	7.5
Do	do	72	1.0085	--------
Do	do	72	1.0094	--------
Megalonaias gigantea	Washboard	4	1.0041	7.6
Do	do	24	1.0025	7.5
Do	do	48	1.0020	7.5
Obliquaria reflexa	Three-horned warty-back	72	1.0033	7.9
Do	do	72	1.0066	7.7
Do	do	72	1.0088	7.5
Proptera laevissima	Paper shell	72	1.0045	7.8
Actinonais carinata	River mucket	4	1.0036	7.8
Do	do	72	1.0046	7.7

NEAR FREEZING

The use of ice in connection with shipments of mussels has been accepted rather generally because the melting ice bathes the mussels continuously in a limited amount of water, without the disadvantages of a water shipment. Accordingly 60 mussels were packed on ice in perforated containers immediately after the animals were taken from the river. The containers were so prepared that no water could accumulate under or around the mussels, but they were kept moist by the constantly melting ice. Blood samples from these mussels were taken at intervals and the data are presented in Table 17 and Figure 14 in conjunction with the data from the other air series.

During the first 48 hours only those animals which were closed were used for samples, and these were found on opening to have lost most of the water which was included between the valves at the time the mussels were taken from the river. At the end of 72 hours exposure to air on ice, all animals still showing tactile responses to stimulation of the foot or mantle were sacrificed for samples. At this time practically all of the mussels were gapping slightly and the water from the inside of the shell had been lost.

In this group of animals kept on ice in air for 72 hours a blood specific gravity of 1.0099 was recorded for a specimen the monkey face, *Quadrula metanevra.* This was the highest blood specific gravity found in any of these studies on the blood of fresh-water mussels. All of the individuals surviving the ice treatment for 72 hours yielded blood with a specific gravity well above the average blood specific gravity for normal mussels, and several records were unusually high. The pH value of the blood of these mussels of the ice series was less alkaline than normal, and in the main the mussels gave the combined picture of blood concentration and low alkalinity which was exhibited by moribund mussels throughout the various tests.

The ice tests were repeated several times on other series of mussels, and it was always noted that as the animal became chilled there was a tendency for the adductor muscles to relax slightly. As the muscles relaxed the shells gapped apart more or less, and the water included between the valves at the time the animal was closed was lost more or less completely. The rise in blood specific gravity in mussels exposed to air seemed therefore, in part at least, to be associated with loss of this water from between the shells. Once the mussel became so numbed that its valves began to gap open, the soft parts of the animal were exposed to the direct action of the air, if the water between the valves were lost. There seemed to be no mechanism to maintain the concentration of the blood at the normal level while the soft parts lost water to the air.

To test this interpretation of these results, four large southern floaters, *Anodonta limneana*, were prepared by cutting a window in the shell of each in the region of the heart, as described in a previous section. Each mussel was then mounted on its side with the uncut valve down, in a glass jar, and water added until the uncut valve and the opening between the two valves were submerged. In this way the mantle cavity of the mussel was filled with water, but water could not enter the shell-window which was above the water level at all times. A thermometer was inserted through the window and supported so that the bulb of the thermometer remained in the pericardial cavity, registering therefore the temperature of the fluid surrounding the heart. The glass vessel was then covered to eliminate disturbing air currents and to reduce evaporation from the mussel to the minimum, and each animal held at 20° C. for six hours before the initial blood sample was taken. The blood samples were drawn directly from the heart, as in previous tests, with a fine dental needle mounted on a Leur syringe.

By adding ice to the water in the jar, the temperature of the animal as determined from the pericardial fluid, was reduced at the rate of 5° C. in 30 minutes. After the mussel's body temperature had been reduced to 0° C. and the last sample taken, the mussel was slowly returned to a temperature of 15° C. to 20° C. where it was held until the following morning (approximately 24 hours after the first sample was drawn), when samples were drawn again during a second reduction of body temperature similar to that of the first day. In the case of mussel C, samples were taken at the beginning and at the end of a third temperature reduction during the third day. After the last samples were taken each mussel was held at room temperature for 24 hours as a check on its condition. None of the mussels of this series died during the 24 hours following the termination of these tests.

The data from this series are given in Table 18.

Table 18.—*Specific gravity of the blood of fresh-water mussels at various temperatures*

Individual		20° C.	15° C.	10° C.	5° C.	0° C.
A	first day	1.0022	1.0012	1.0016	1.0022	1.0010
	second day	----------	1.0017	1.0022	1.0021	----------
B	first day	1.0020	1.0012	1.0012	----------	----------
	second day	----------	1.0016	1.0014	1.0018	----------
C	first day	----------	1.0005	1.0008	1.0010	----------
	second day	1.0005	1.0005	.0015	1.0021	1.0018
	third day	1.0010	----------	----------	1.0015	----------
D	first day	1.0010	1.0012	1.0014	1.0012	----------
	second day	1.0015	1.0017	1.0021	1.0016	1.0019

The figures given in Table 18 show that the specific gravity of the blood did not rise to the levels attained by the blood from the mussels of the ice series in which no precaution was taken to prevent undue loss of water by the mussel. In fact, there was little or no concentration of the blood, as measured by the specific gravity, in these floaters which were protected from air currents and loss of water, although they were lowered to zero centigrade.

The changes in the blood specific gravity of the mussels when held in air are evidently a matter of water loss to a large extent, as the mussel seems to have no way to maintain the blood concentration level when water is removed from a large portion of the body. The changes in the alkalinity were not evident in the blood until the animal became moribund as the result of the water loss.

SUMMARY

Blood from 27 species of North American fresh-water mussels was analyzed and the values of the various characteristics and constituents of normal fresh-water mussel blood determined. These values have been summarized in Table 19.

Table 19.—*Summary of the characteristics and constituents of normal fresh-water mussel blood*

	Minimum	Average	Maximum		Minimum	Average	Maximum
Specific gravity	1.0003	1.0026	1.0078	Calcium chloride per cent	0.0087	0.0270	0.1060
Total solids per cent	.3436	.4260	.4965	pH	7.4	7.9	8.5
Total ash do	.1256	.1539	.2820	Blood gases:			
Organic material do	.1190	.2721	.3145	Oxygen volumes per cent	.16	.39	.89
Blood sugar milligrams	7	32	93	Carbon dioxide do	.09	.43	.81
Sodium chloride per cent	.0310	.1090	.2950	Nitrogen do	1.08	1.34	1.80

These values collectively show the blood of fresh-water mussels to be very low in solids as compared with the blood of other animals, both fresh-water and marine. The blood of fresh-water mussels is more alkaline than that of most animals, and varies over a rather wide range on the alkaline side of neutrality; in this respect the blood of fresh-water mussels being comparable to that of other mollusca as noted by Giersback (1891).

Although the blood of fresh-water mussels was found to contain only very small quantities of inorganic salts, it was demonstrated by means of physiological tests on living preparations of the foot and of the heart of fresh-water mussels, that these salts, even though present in the blood in low concentrations, are essential for the life activities of the mussels; and that these salts are balanced against each other as in the higher animals. The activity of the heart and of the foot of these fresh-water mussels ceased promptly if the proportions or the quantities of these salts in the blood were increased or diminished beyond rather narrow limits.

The fresh-water mussels were found to be very sensitive to changes in the salt content of the water in which they were living. When small quantities of common salt or various other inorganic salts were added to the surrounding water, the specific gravity and salt content of the blood of the mussels changed rapidly in a few hours. Similarly if the mussels were transferred from ordinary river water to distilled water, the specific gravity and salt content of the blood of the mussels were lowered. From these series of tests it was demonstrated that the blood of the fresh-water mussel varies with and in the direction of the concentration of the salts in the water in which it is living; and as these changes take place rapidly, they suggest that the restriction on an osmotic balance between the blood of the mussel and the fluid surrounding the mussel is slight. Since the fresh-water mussel is very limited in its locomotion, this facile modification of the blood by the environment makes the fresh-water mussel particularly susceptible to changes in water composition resulting from the introduction of various industrial wastes into the mussel-bearing streams.

Exposure to air either at ordinary temperatures or on ice, caused the specific gravity of the blood of fresh-water mussels to rise, indicating a concentration of the blood. This concentration of the blood, which rapidly reached a critical level, was accelerated if the mussel lost the water which was retained inside of the shell when the animal was removed to the air. As mussels packed on ice were soon so numbed that the adductor muscles relaxed sufficiently to allow the shells to gape open and the water to drain out, mussels so packed succumbed more rapidly than those which were packed in moist sphagnum or other damp material.

The alkalinity of the blood was reduced and the specific gravity rose in moribund fresh-water mussels.

The blood can be used as an index of the physiological condition of fresh-water mussels.

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THE RELATIVE GROWTH AND MORTALITY OF THE PACIFIC RAZOR CLAM (*SILIQUA PATULA*, DIXON), AND THEIR BEARING ON THE COMMERCIAL FISHERY[1]

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INTRODUCTION

The present paper is a continuation of previous work on the economically important mollusks of the Pacific coast of North America. The earlier studies of the senior author on the bivalves of California led to the development of a method of determining age and thus made possible an accurate study of growth. The seasonal growth shown for the Pismo clam has since been substantiated in other species, for example, in *Anodonta*, Thiel (1928) found practically no increase in length during the entire winter. This method of age determination based on the annual rings of the shell was later successfully applied to the Alaska razor clam (fig. 1) which was showing signs of depletion (Weymouth, McMillin, and Holmes, 1925). In the present report the accumulated data on the growth of this species over a wide range of latitude has been analyzed in greater detail. It is clear that in all parts of the coast, where the razor clam is fished commercially, supervision is necessary to maintain this valuable resource. It has become equally clear that the course of growth, breeding habits, and the like vary so widely in different parts of the coast that the regulations must be adapted to the district. Thus in Alaska the set of the young clams seems never to be more than a fraction of that on the Washington beaches, and the growth is much slower. For example, the clams reach the breeding size in two years at Copalis on the Washington coast but require four years at Swickshak, Alaska. The smaller set and slower growth of the clams make the northern beds less resistant to heavy fishing

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[1] Submitted for publication Sept. 18, 1930

and slower to return to productivity when depleted. The importance of this knowledge for protective regulations as well as for its intrinsic biological interest makes desirable the analysis here attempted.

THE GENUS SILIQUA

The primary purpose of the present paper is an analysis of the growth data now accumulated for the Pacific razor clam. The first question to be considered is that of the homogeneity of the material studied. The Pacific razor clam belongs to the genus *Siliqua* of the family *Solenidæ.* This genus includes at least 12 species found along the shores of the entire North Pacific from Lower California north to Bering Sea and south on the Asiatic side to the Malay Archipelago. The type of the genus (*Siliqua radiata*) extends into the Indian Ocean and two species are found on the North Atlantic coast from the Arctic down to Cape Hatteras. In the initial report we briefly discussed the systematic relations of certain of these species (Weymouth, McMillin, and Holmes, 1925). More intensive work has convinced us of the validity of our former conclusions. Briefly, we consider that there are four species of *Siliqua* on the west coast of North America: *S. media,* found in Bering Sea and Arctic Ocean; *S. alta,* in Cook Inlet and westward to Bering Sea and Siberia; *S. patula,* from the Aleutian Islands to Pismo, Calif.; and *S. lucida,* from Monterey, Calif., to Lower California. All authorities agree that *S. media* and *S. lucida* are distinct species. The present view differs from that of Dall (1899) in two respects. *S. patula* var. *nuttallii* and typical *S. patula,* which he considers connected by gradiations, we are unable to separate on reliable criteria and are forced, therefore, to deny to *nuttallii* even subspecific rank. *S. patula* var. *alta* considered by Dall as a variety of *S. patula,* we find undoubtedly entitled to specific rank. A more detailed discussion of these species and their relationships is to be presented elsewhere.

We have arrived at the above conclusions after extensive observations on razor-clam beds from San Diego to the Bering Sea. We have dug and handled large numbers of animals and have carefully measured over 6,000 shells, the majority of these measurements being made under laboratory conditions. In addition to the data on form to be presented later, there are differences in the living animal which clearly indicate that *S. alta* represents a distinct species.

The most notable character in *S. alta* is the pigmentation. All exposed parts of the mantle, siphon, and foot are colored by a chocolate-brown pigment which immediately distinguishes it from *S. patula,* which is entirely without this coloration. The siphons of *S. alta* are short and thickly studded with tubercles which become longer near the opening. The siphons of *S. patula* are less closely fused and have a distinct tendency to separate near the openings, the exhalant siphon being the longer. They also lack the tubercles and do not have as long tentacles about the siphon openings. *S. alta* is found higher on the beach and owing to its short siphon lies nearer the surface. These differences and the distinctive pigmentation in *S. alta* make it possible for the commercial clam diggers to recognize these two species readily and to avoid taking *S. alta.*

DIFFERENTIAL GROWTH RATIOS IN SILIQUA PATULA AND S. ALTA

Since the shape of the shell is an important specific character in the genus *Siliqua,* an analysis of the variations in form of the material studied was necessary. Accordingly, not only the length but also, in many cases, the width and the distance

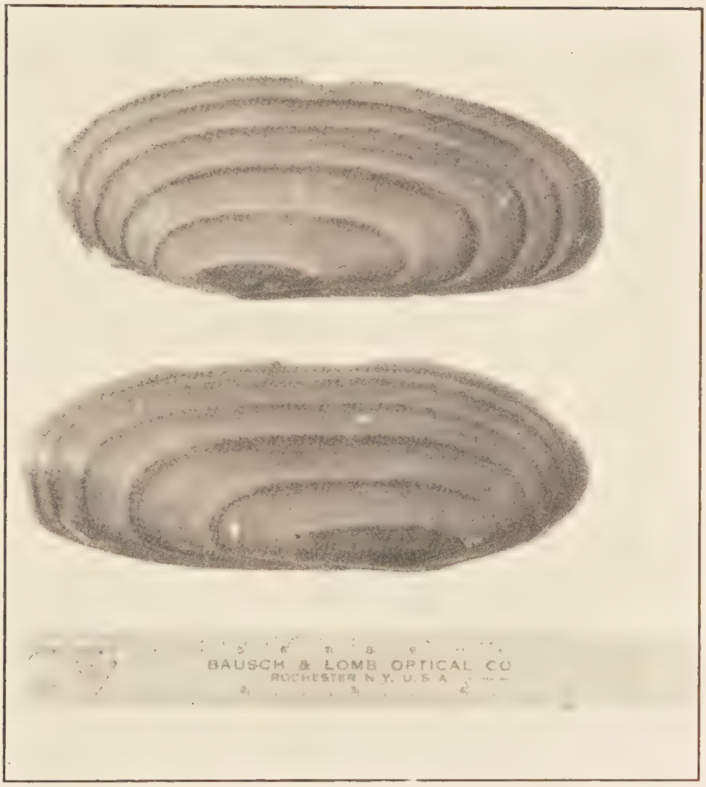
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Figure 1.—*Siliqua patula* Dixon (photo by O. W. Richards)

from the umbo to the posterior end of the shell were measured. In a smaller number of cases the ventricosity or transverse diameter, the length of the ligament bed, and other dimensions were determined but these proved less useful.

Although the form of animals, as, for example, the head length and size of eye in fish, have been used in systematic work, too little attention has been paid to the variability and the changes of form with age. In recent years Huxley and some of his students (1924, 1927, 1927a) have made a series of notable studies of animal form. They have found that in most cases the relation between part and whole may be represented by the formula

$$y = bx^k,$$

where y is the length (or weight) of the part, and x that of the whole.

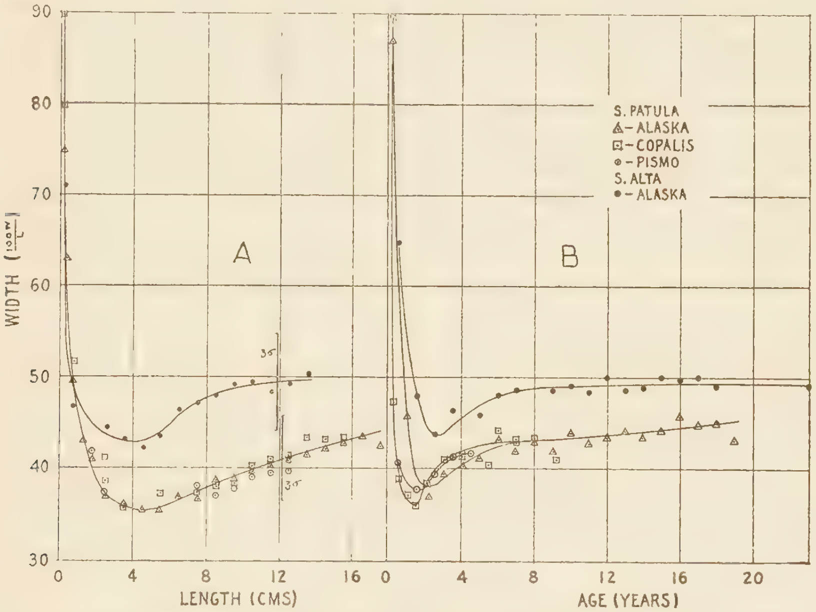

FIGURE 2.—Average percental width of *S. patula* from California, Washington, and Alaska, *S. alta* from Alaska. A, For each centimeter of length; and B, for each year of age

If a constant relation of this type persists throughout life we may distinguish two cases. In one the exponent k is unity and the formula becomes

$$y = bx;$$

that is, the part bears a constant relation to the whole, and the form does not change with size. This, Huxley calls "isogonic" growth. On the other hand, k may be greater or less than unity, indicating that the part is increasing or decreasing in relation to the whole, a type of growth called by Huxley "heterogonic." Of course, neither condition may exist through life, but the differential growth ratio may change.

WIDTH

In order to present the length-width relation in the clam, we have calculated the percental width of the shells in a series of 1,330 individuals of *S. patula* and *S. alta*. These results are given in Tables 1 and 2 and presented graphically in Figure 2.

Growth is clearly not isogonic. The young of both species are nearly round, but undergo a rapid change in shape as they grow, becoming greatly elongated. This reduction in width continues until the shell is about 5 centimeters in length, when *S. patula* has a width of about 36 per cent and *S. alta* a width of 42 per cent. During the remainder of the life of the clam the shell becomes wider until in the oldest specimens of *S. patula* the width measures 42 per cent of the length and in *S. alta* about 50 per cent.

Treated by Huxley's method of plotting the logarithm of the width on the logarithm of the length we obtain a consistent picture, *k* is at first less than unity (0.6) and gradually increases, reaching a value of 1 at five or six years (minimum of the above curve) and finally attaining a value of about 1.2. It will be noticed further that specimens from all parts of the coast have the same proportional width of shell. One exception is recorded: The largest shells from Pismo, Calif., show a tendency to be narrower than those from other localities. This difference, however, but slightly exceeds the probable error and is, therefore, of doubtful significance but may be interpreted as an effect of age on the proportional width. This would be comparable to our findings on sexual maturity, which occurs at essentially the same length on different parts of the coast, although at widely different ages (Weymouth, McMillin, and Holmes, 1925). Nevertheless a minor effect of age on sexual maturity can be traced, and it would be reasonable to expect a similar effect on relative width.

TABLE 1.—*Average width of Siliqua patula from California, Washington, and Alaska, and of Siliqua alta from Alaska, for each centimeter of length*

Length in centimeters	S. patula						S. alta	
	Alaskan		Copalis		Pismo			
	100 W/L	Number of specimens	100 W/L	Number of specimens	100 W/L	Number of specimens	100 W/L	Number of specimens
17.0–17.2	42.5	2						
16.0–16.9	43.6	14						
15.0–15.9	42.9	19	43.5	2				
14.0–14.9	42.1	29	43.3	8				
13.0–13.9	41.5	21	43.4	28			50.3	12
12.0–12.9	41.0	18	41.5	34	39.7	23	49.3	62
11.0–11.9	40.5	18	41.1	37	39.5	36	48.4	31
10.0–10.9	39.9	44	40.3	9	39.0	8	49.5	16
9.0–9.9	38.8	55	38.2	12	37.8	54	49.3	14
8.0–8.9	38.7	31	38.1	13	38.1	33	47.9	15
7.0–7.9	36.9	33	37.5	7	38.0	10	47.2	10
6.0–6.9	36.8	21					46.5	10
5.0–5.9	35.3	12					43.5	17
4.0–4.9	35.3	20	37.3	6			42.2	21
3.0–3.9	36.0	16	35.8	4			43.2	9
2.0–2.9	36.9	33	38.5	8	37.2	38	44.5	7
1.5–1.9	41.0	24	41.0	11	41.9	79		
1.0–1.4	43.1	101					46.8	17
0.5–0.9	49.6	67	51.6	14			51.0	7
0.3–0.4	63.0	12	63.2	3				
0.1–0.2	75.0	7	79.8	3				
0.0–0.1			89.6	3			71.0	2

TABLE 2.—*Average width of Siliqua patula from California, Washington, and Alaska, and of Siliqua alta from Alaska, for each year of age*

Age, years	S. patula						S. alta	
	Kukak		Copalis		Pismo			
	100 W/L	Number of specimens	100 W/L	Number of specimens	100 W/L	Number of specimens	100 W/L	Number of specimens
23							49.0	1
19	43.0	2						
18	45.0	2					49.0	2
17	44.8	3					50.0	3
16	45.8	9					49.7	9
15	44.2	33					50.0	14
14	43.5	21					48.8	14
13	44.2	29					48.6	17
12	43.4	37					50.0	12
11	42.8	29					48.5	14
10	44.0	27					49.2	7
9	42.0	6	42.0	4			48.7	3
8	43.0	6	43.3	12				
7	42.9	19	43.3	10			48.8	5
6	43.2	14	44.3	5			48.2	3
5	41.2	3	41.0	10	[1] 41.8	1	46.0	7
4	40.2	39	41.7	22	[1] 41.3	8	[1] 46.5	28
3	39.5	123	41.0	39	[1] 39.4	60	[1] 43.9	42
2	38.2	13	38.6	39				
1.5			36.0	6	37.9	97	48.0	24
1	45.8	2	37.2	11				
0.5			39.0	6	40.8	117	65.0	4
0.2			47.5	27				
0.1	87.1	6	89.6	3				

[1] Ring measurement: For correct age subtract one-half year.

In the foregoing comparisons of the form of *Siliqua patula* and *S. alta* we have used the average of each group. For the length of 11 and 12 centimeters sufficient material is available to show the variability. Here it is found that some specimens of *S. patula* were wider than some of *S. alta*. There is an overlapping between the two distributions which is found to amount to 6 specimens in 200, or 3 per cent of the entire number of clams of these lengths. There can be no doubt of a significant difference in relative width.

POSITION OF UMBO

By measuring the distance from the umbo to the posterior end of the shell, and expressing this as a per cent of the total length of the shell a numerical value for the location of the umbo is obtained. For *S. patula* from all parts of the coast this ratio is constant at any given length. During the period of rapid growth of the clam the umbo shifts toward the posterior end, indicating a relatively greater growth of the anterior end. After a length of 10 centimeters has been reached, the proportion of the length of shell on either side of the umbo is constant. (Table 3.)

Comparable data are available for *S. alta* larger than 10 centimeters. In this species the umbo is more anterior than in *S. patula*. The anterior position of the umbo in *S. alta*, together with the narrower anterior end of the shell, gives it a distinctive appearance by which it can easily be separated from *S. patula*.

TABLE 3.—*Position of the umbo at each centimeter of length for Siliqua patula and Siliqua alta*

Length	Position of umbo		Length	Position of umbo		Length	Position of umbo	
	S. patula	S. alta		S. patula	S. alta		S. patula	S. alta
Centimeters			*Centimeters*			*Centimeters*		
0.0–0.9	71.43	----------	6.0	70.38	----------	12.0	67.33	74.44
1.0	70.75	----------	7.0	70.25	74.50	13.0	67.73	74.67
2.0	72.83	----------	8.0	69.20	72.50	14.0	68.65	76.00
3.0	72.67	----------	9.0	68.00	72.00	15.0	67.70	----------
4.0	71.67	----------	10.0	67.86	74.25	16.0	68.25	----------
5.0	71.00	----------	11.0	67.17	74.29	17.0	67.25	----------

DIRECTION OF RIB

One very noticeable character of the shell is the direction of the rib. If the shell is opened until the two valves lie in the same plane, the two ribs of *Siliqua alta* form nearly a straight line, but those of *S. patula* lie at a distinct angle. The direction of the rib from the umbo was measured by placing the dorsal margin of the shell on the table and reading from a protractor the angle between the table anterior to the umbo and the posterior margin of the rib. The results show a small individual variation which can not be correlated with age or size. In *S. patula* the angle is between 69° and 84°, in *S. alta* between 84° and 90°.

From this study we are convinced that there are four species of the genus *Siliqua* on the west coast of North America. These include, in addition to *S. media* and *S. lucida*, generally recognized, *S. alta* and *S. patula*. The only species considered in the present growth study is *S. patula*.

An additional conclusion applicable to other animals may be drawn from this study of body proportions. It is useless for comparative purposes to state the ratio between the measurements of any two parts of the body, such as length and width of the shell in the present case, or the head and the body length of a fish, unless the total size or age is also given. The variation of these ratios with size and age can not be foretold but must be determined for each species; they are, in the razor clam, so considerable that they can not be ignored. The greatest variation occurs in clams below 5 centimeters in length; but if we disregard these, the larger ones still are widely variable. If we deal with what may justly be considered "adult" specimens, the change in proportional width of either *S. alta* or *S. patula* with size is as great as the differences between the species. In other words, while specimens of the same length show an average difference in width which no one would hesitate to call specific, large specimens of *S. patula* may be selected giving the same average width as those of small *S. alta*. This fact should be borne in mind by systematists in framing specific descriptions.

SILIQUA PATULA

VARIABILITY

The variability of each age class of clams has been measured in terms of "D" or interdecile range (Kelley, 1921) as the most appropriate measure to accompany the median. This may readily be visualized as the range in length of the central 80 per cent of each frequency distribution.

This value for all ages and localities is given in Table 8. For four typical localities Figure 3 shows "D" plotted on length. It will be seen that the absolute variability rises to a maximum after which it again declines to become fairly constant in the larger sizes (12 to 16 centimeters). The maxima fall at widely different ages but at a common length of 5 to 8 centimeters. The highest absolute variability therefore corresponds in general to the period of most rapid growth but in all cases occurs somewhat after the inflection.

If the relative variability is calculated, a different picture is obtained. The interdecile range expressed as a per cent of the median $\left(\frac{100\,D}{Mi}\right)$ is very large in the younger stages, for example at a length of 0.35 centimeter it is over 200. From these high values it falls throughout the available life history until in large clams it is less than 15 per cent of the length.

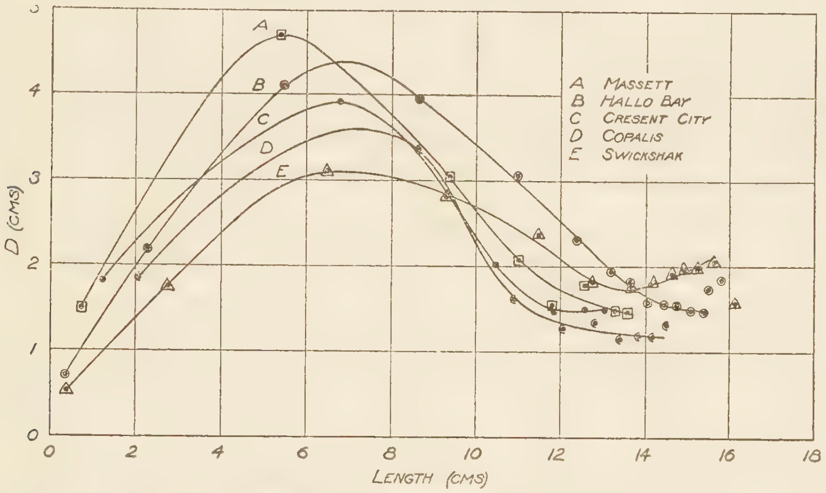

FIGURE 3.—The variability (D) of each length of clams from five localities

SEXUAL DIFFERENCES

In the curves here presented the sexes have not been considered separately except in three localities. The shells of the two sexes are indistinguishable, and hence identification requires the examination of fresh material in which the eggs or sperm may be recognized by a hand lens. In order to see if sexual differences in size or weight were apparent, growth curves were constructed for three localities. At Swickshak 152 males and 150 females between the lengths of 7.50 and 12.25 centimeters were measured. During the period of most rapid growth the differences were too slight and inconsistent to be of significance in spite of the fact that at this time such differences are greatest.

A series of 115 males and 113 females were available from Hallo Bay (Table 4); and since greater and more consistent differences were found in these than in other material, the two curves are reproduced in Figure 4. At the first winter the males average slightly the larger. During the period of most rapid growth, in this case from 2 to 9 years, the males are the shortest and the curves then again cross, the two sexes having the same length during the tenth, eleventh, and twelfth years after which again the males are longer, though the differences are less marked than in the period of rapid growth. Incidentally the mortality of the females is higher as shown by the fact that the males outnumber them from 8 years on, and that from 16 to 19 years only males are represented, although the numbers are small.

TABLE 4.—*Median lengths of males and females from Hallo Bay to correspond with Figure 4*

Ring number	Males		Females		Ring number	Males		Females		Ring number	Males		Females	
	Length	Number of specimens	Length	Number of specimens		Length	Number of specimens	Length	Number of specimens		Length	Number of specimens	Length	Number of specimens
	Cm.		*Cm.*			*Cm.*		*Cm.*			*Cm.*		*Cm.*	
1	0.39	37	0.32	54	8	13.56	97	13.76	95	15	15.85	15	15.67	12
2	2.07	111	2.48	115	9	14.05	93	14.07	89	16	15.62	8	15.50	2
3	5.05	113	6.22	116	10	14.44	88	14.46	84	17	15.74	4	--------	------
4	8.01	113	9.21	116	11	14.77	73	14.77	65	18	16.31	3	--------	------
5	10.59	112	11.33	116	12	15.13	57	14.98	54	19	16.74	2	--------	------
6	12.21	111	12.59	116	13	15.42	42	15.28	35					
7	13.10	105	13.27	106	14	15.60	28	15.42	24					

Whether the greater difference in the size of the males and females in this series is peculiar to the locality or whether the method of taking the shells did not give an accurate sample, it is impossible to determine. The shells were taken from two lots of clams which may have come from different localities. One sample contained over one-half males and the other a larger number of females, so the significance is doubtful. However, these results are similar to those of Copalis, Wash., although the differences are more marked. The curves in the latter case cross and recross in a similar manner at corresponding periods in their life cycle. Differences in the growth curves of the sexes in mollusks have been described by Chamberlain, who found the course of growth to vary between sexes of fresh-water mussels [2] (1931). In this case, however, the sex is indicated by the shape of the shells, and one can easily determine the sex of the animal from its appearance, while in razor clams weights and proportional measurements of the shell do not show sexual differences. Since the number of each sex is approximately equal, it is assumed that a composite curve calculated from growth records of both sexes, if taken in a limited habitat, is adequate for growth study.

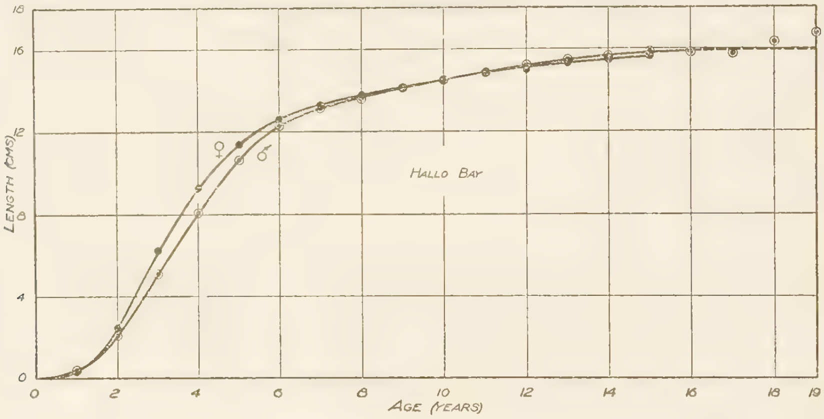

FIGURE 4.—Growth curves for males and females taken in Hallo Bay, Alaska. Age is indicated as ring number; to determine actual age subtract one-half year

MORTALITY

One striking feature in the study of clams from all parts of the coast is the difference in age found between northern and southern beds. No clams over 5 years old have been found at Pismo, Calif. The Washington beds produce clams up to 9 years of age, while the commercial catch in Alaska contains a large number of 13-year-old clams and ages up to 19 years have been recorded. In order that any valid comparison of age may be made it is necessary that mortality data in the form of survival curves be available.

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[2] Thesis, Stanford University.

TABLE 5.—*Survival table showing numbers of clams still living at each age for each 100 clams forming first ring, and age of 5 per cent survival for each locality*

Year	Pismo	Crescent City	Channel	Sink	Copalis	Massett	Controller Bay	Karls Bar	Swickshak	Hallo Bay
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	92.0	98.0	97.3	97.3	98.5	98.7	99.0	98.3	97.6	98.3
3	53.7	93.6	91.1	96.4	91.3	95.8	99.0	97.0	97.6	96.2
4	10.5	88.1	62.8	88.6	83.6	93.4	99.0	96.5	89.6	96.2
5	1.7	79.3	30.4	76.5	71.1	71.8	97.8	94.4	84.3	95.8
6	---------	60.3	11.9	29.6	53.8	54.7	89.1	87.3	80.4	95.3
7	---------	20.9	9.2	2.6	37.1	47.7	71.8	86.0	76.9	88.7
8	---------	4.4	1.1	1.8	17.2	33.0	48.2	54.3	72.0	80.7
9	---------	.6	---------	---------	3.8	12.2	15.9	24.0	62.5	76.9
10	---------	---------	---------	---------	---------	2.0	7.4	14.6	58.6	72.2
11	---------	---------	---------	---------	---------	---------	6.1	9.7	44.8	58.0
12	---------	---------	---------	---------	---------	---------	3.7	5.8	27.2	46.7
13	---------	---------	---------	---------	---------	---------	1.2	3.2	9.5	32.3
14	---------	---------	---------	---------	---------	---------	---------	1.3	1.8	21.8
15	---------	---------	---------	---------	---------	---------	---------	1.3	.4	11.4
16	---------	---------	---------	---------	---------	---------	---------	1.3	---------	3.0
17	---------	---------	---------	---------	---------	---------	---------	1.3	---------	1.3
18	---------	---------	---------	---------	---------	---------	---------	---------	---------	1.3
19	---------	---------	---------	---------	---------	---------	---------	---------	---------	.9
Age (years) of 5 per cent survival	4.4	7.9	7.0	7.0	8.8	9.6	11.0	12.0	13.4	15.6

This need we were forced to supply from age-frequency data from the different beds. We have assumed, as did Lea for the herring (1924), that the frequency of the older ages represents a practical survival curve for that locality and have supplied the earlier portion by comparison with those based on the most adequate data. In the resulting curves for each locality, we located the smallest survival that could be accurately determined, which proved to be 5 per cent. This we have arbitrarily taken as the maximum age. (See Table 5.) The comparison of different localities is discussed in a later portion of this paper.

GROWTH

The data on the growth of the razor clam here presented were collected over a period of years from 1923 to 1928. We consider them unique in that the growth of a single species is recorded from 10 different localities, making possible a comparison of the general course of growth under the widely differing environments involved in 2,400 miles of coast and 25° of latitude. We propose to consider (1) certain significant general tendencies common to all localities and to other animals, and (2) certain less significant differences due to the environment.

As explained in former papers (Weymouth, 1923, 1923a; Weymouth, McMillin, and Holmes, 1925), the seasonal growth of the clam leaves its record in the shell as a series of age marks so that it is possible to measure not only the length of the shell at the time it was taken, but also its actual length at each previous winter of its life. We have thus available a complete record of the growth of the individual usually only obtained if the animal is reared and observed throughout life. Therefore, the norms of growth which we present are not based solely upon the size of the individuals gathered at a certain time but chiefly upon the median values of a large series of records of individuals throughout their entire lives.

The number of measurements each representing the length of a clam at a known age is such as to inspire confidence in the statistical results. Although many others have been measured, 13,797 lengths have been used in the growth curves here considered.

LENGTH AS A MEASURE OF SIZE

Length has been selected as the basis of this growth study because, in the present case, we consider it the best measure of size. Calipers with which accurate measurements of length may be made rapidly are easily used in the field where equally accurate scales can not be carried. The weight of clams varies widely, owing to two causes. The sinuses of the foot and the mantle cavity hold a variable amount of water which may or may not be lost at the time of digging. The sexual products of the clam comprise 10 to 30 per cent of the total weight, and further error in weight is introduced by seasonal fluctuations in the amount of spawn developed. Not only are solid structures, such as shell and bone, incapable of reversal so that a decrease of length in contrast to weight does not normally occur, but growth in length persists under unfavorable circumstances when it can only take place at the expense of weight, as Podhradsky and Kostomarov (1925) have shown in starving carp. Because less error is involved in its determination and because it is a more conservative and persistent process, increase in length is not only the more convenient but also the more significant biological measure of growth.

LOCALITIES STUDIED

As an aid in the consideration of the growth curves from various beds, the name and location, together with a brief description of each place, are here included:

Pismo, Calif., (*lat. 35° 11′ N.*).—The beach is of considerable extent and represents a normal habitat—a wide pure sand beach exposed to surf. Pismo represents the practical southern limit of this species; although occasional shells are found farther south, these were not abundant enough for growth data.

Crescent City, Calif., (*lat. 41° 45′ N.; 500 miles from Pismo*).—The bed just south of the city is of fine and coarse sand with some fine gravel; the beach is broad and exposed to surf. We consider it a normal habitat.

Copalis, Wash., (*lat. 46° 58′ N.; 860 miles from Pismo*).—This is an extensive and surf-washed beach of pure sand which, as we shall see, must be considered particularly favorable. The "Channel" and the "Sink" at Copalis are two local habitats selected because distinctly atypical. The "Channel" bed is located on the entrance to Grays Harbor, where there are strong currents and the beach is steep and gravelly. The "Sink" bed is near the mouth of a lagoon cut off by the formation of a bar consequent to the building of a jetty. It lacks surf and there is much mud in the sand.

Massett, British Columbia (*lat. 53° 20′ N.; 1,380 miles from Pismo*).—On Queen Charlotte Island between Massett Inlet and Rose Spit the beach is broad and of pure sand. Although not directly exposed to surf, all northerly wind causes small breakers over the beds. It is the only bed of commercial importance in British Columbia. Specimens were taken the second year of commercial operation.

The Alaskan beds are on or adjacent to the Gulf of Alaska and their relative position requires a word of explanation. The coast of the gulf trends north and west, reaching the most northern position near Cordova; after which it sweeps again to the south and west, so that the beds on Shelikof Straits (Swickshak and Hallo Bay) lie about 2° farther south than those near Cordova (Controller Bay and

Karls Bar). The isotherms follow in general the sweep of the gulf but the beds in Shelikof Straits lie north of the mean annual isotherm of 40° F. which passes approximately through those near Cordova. For this reason we have used the position along the coast measured in miles rather than the latitude as indicating the geographical position.

Controller Bay, Alaska (*lat. 60°; 2,040 miles from Pismo*).—This bay is a broad shallow body of water, with much of the bottom exposed at low tide. The upper part of the bay is covered with fine glacial mud, and the outer bars are of sand with some glacial mud. During the summer the Bering River empties a large amount of glacial drainage into the bay, making the water cold and filled with muddy silt. We consider Controller Bay a very unfavorable habitat. The beds will not support commerical operations.

The clams furnishing the Karls Bar growth curve were taken from a small portion of the beds in Orca Inlet near Cordova (lat. 60° 27′ N.; 2,105 miles from Pismo). The soil is fine sand with some glacial silt. The bed is not exposed to the surf; and, although it differs greatly from the southern beds, it is typical of the Alaskan clam-producing areas. The beds in this vicinity have been dug for 12 years, but the area from which these specimens were taken had not been previously exploited.

Swickshak, Alaska (*lat. 58° 5′ N.; 2,405 miles from Pismo*).—This bed is on the north of Shelikof Straits opposite Kodiak Island. The beach is of fine sand and volcanic ash and is more exposed to surf than most of the northern beds. This bed was first dug in 1923 and our material was taken during that year and in 1924.

Clams are taken in Hallo Bay (lat. 58° 5′ N.; 2,425 miles from Pismo) on the northern shore where it is protected by the island in the bay. The beach is of sand, volcanic ash, and glacial mud. The shells were taken from among the first clams dug in that place.

QUANTITATIVE TREATMENT OF DATA

We may define growth as increase in size and take, in the present case, length as a measure of size. Quantitative data on the length of the clam will be considered. This may be presented as absolute growth; that is, average total size at each age or the gross annual increments. Or we may show the relative growth rate; that is, the proportional or percental gains at each age. The graphic representation of growth may be cast, therefore, in two contrasting pictures, both of which contribute to an understanding of growth.

Absolute growth.—We shall first consider absolute growth. In Figures 4, 5, and 6 are presented norms of growth for 10 localities; the corresponding medians are given in Table 8. These are plotted in the usual fashion; that is, they are the regressions of length on age, or average length for each age-group. The converse regression, age on length, is closely similar in early life, but differs significantly in the later years (Weymouth, McMillin, and Rich, 1925).

The length of the first ring varies roughly with the latitude of the beds from which the clams are taken, ranging from one-third of a centimeter in the north to 2 centimeters in the south. These differences appear to result from the higher temperature in the south which favors a more rapid growth and, permitting an earlier spawning, furnishes a longer growing season.

Following the formation of the first ring, growth is rapid. In the southern beds, over two-thirds of the length is reached during the first growing season. In the north growth is slower and a comparable increase requires over four years. In the northern forms it will be noted that the curve of absolute growth rises slowly at first but with an increasing slope up to a certain point, followed by a decreasing slope during the remainder of the curve. This inflection, or point of change from increasing to decreasing slope was not noticed in our early growth studies on the Washington beds. Ultimately a method of fitting, to be discussed later, convinced us that an inflection is present in all, and the curves of absolute growth have been so drawn. The inflection, on the average, is at 22.36 per cent of the maximum age and 32.75 per cent of the total length. There is no obvious correlation between these ages and lengths and any other features of the growth curves as maximum age, maximum length, relative growth rate, or the like.

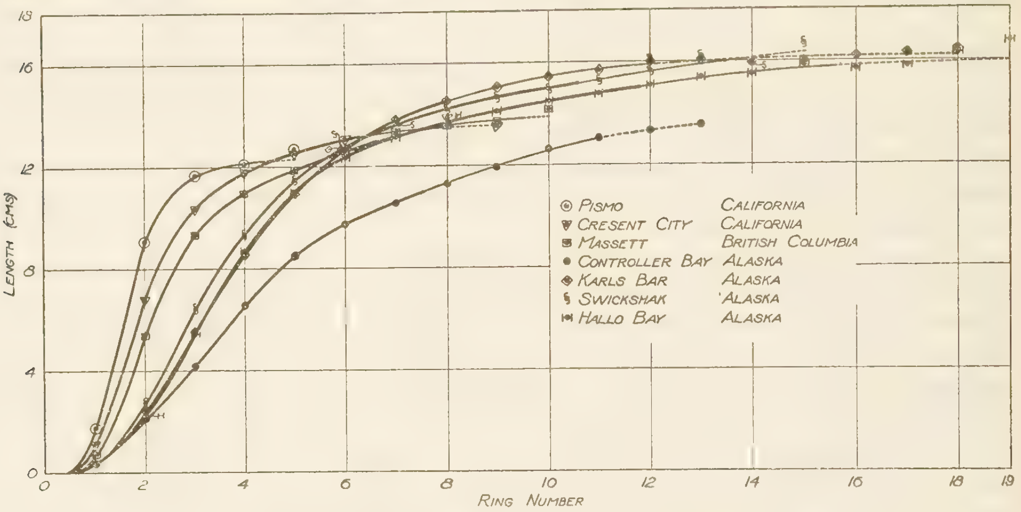

FIGURE 5.—Growth curves from seven localities in California, Oregon, British Columbia, and Alaska. Ages are indicated by ring number; to determine actual age subtract one-half year

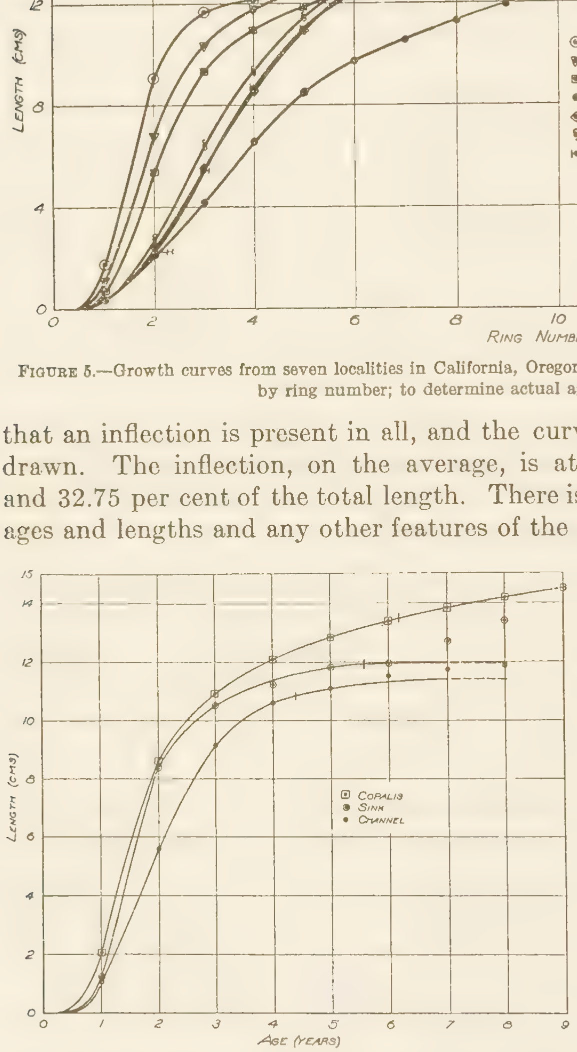

FIGURE 6.—Growth curves for three localities in Washington. Ages are indicated by ring number; to determine actual age subtract one-half year

Following the inflection, the rate of growth decreases regularly until a final adult length characteristic of the locality is reached. This varies from 12 to 16 centimeters, the slower-growing northern clams reaching in general the greatest size and having the longest life.

To show the rate of absolute growth we may plot the annual increments, or differences between successive total lengths, on the age. (Fig. 7.) This shows an increase of rate which reaches a maximum at the point of inflection of the total length curve. This maximum may fall early in life; and, since the smallest time interval available is the year, its location may only be approximated by this method.

Following the maximum, the rate declines throughout life and for a time closely approximates a descending geometric series; that is to say, each yearly growth is a certain percentage of the preceding. This relation was first pointed out by Pütter

(1920) and subsequently for the Pismo clam (Weymouth, 1923a), by Brody (1923), and by Munford (1926) for the growth of various domestic mammals. This relation however fails in old age when the growth is greater than would be predicted on this basis.

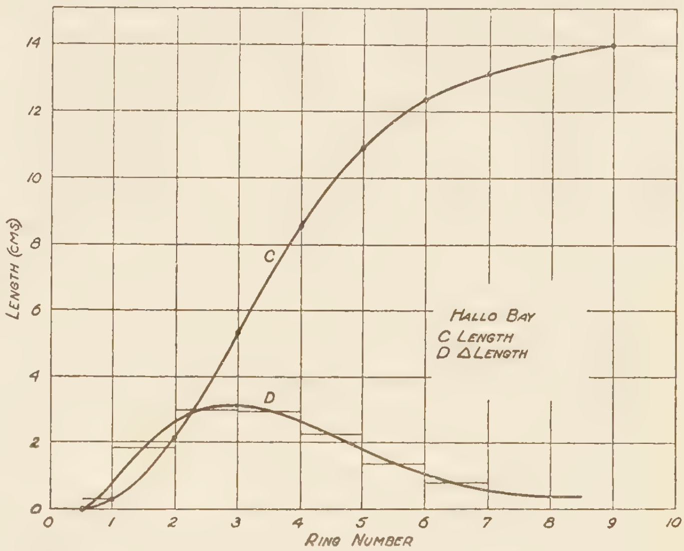

FIGURE 7.—Absolute growth curve of clams from Hallo Bay, Alaska, with the first differential

Relative growth.—To picture the relative or percental growth, recourse may be had to the ratio diagram as used by the economist. Here equal proportional or percental changes are represented by equal vertical distances. Such a diagram is obtained if we plot the logarithms of the total length on age, as in Figures 8 and 10. Such a curve rises most steeply at first, and the slope continually declines throughout life. Or, as before, we may plot the percental yearly gains which show a continually decreasing increment during the period for which we have data. (Figs. 8 and 9.)

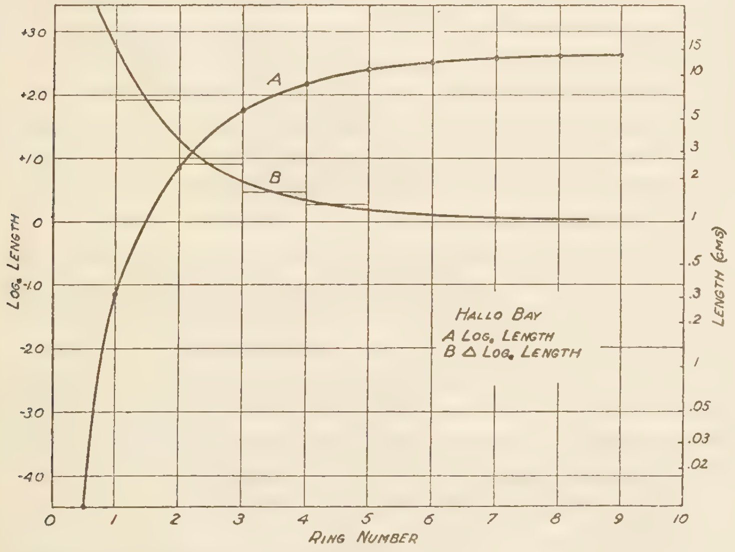

FIGURE 8.—Ratio diagram of growth of clams from Hallo Bay, Alaska, with the first differential

Comparison of absolute and relative treatments.—With these two methods of presentation before us, let us contrast the pictures. The differences lie chiefly in early life; the slow growth of old age differs little whether regarded from the absolute or the relative viewpoint. The early growth, however, appears in a very different light when presented by these contrasted methods. As stated above, the absolute growth of small clams is slow. This later becomes more rapid with its maximum at the point of inflection, after which it again declines. The relative growth, on the other hand, is most rapid at the youngest ages for which we have records and steadily declines with time. Obviously, as with other statistical procedures, both pictures are true and necessary to complete presentation. Which, however, represents the more significant point of view? Unless we are to forget the purpose of quantitative work we must emphasize that method which agrees with the greater number and the more significant qualitative, in the present case biological, facts.

The most significant difference between the two viewpoints relates to the rate of growth. Many physiological processes are considered on a relative basis. To use a familiar example, the metabolic rate is measured by the oxygen consumption or the heat production per unit of time per unit of weight or of body surface. This is obviously necessary to permit the comparison of rates in animals of widely differing sizes. Minot early recognized and clearly stated the biological significance of the relative growth rate which he expressed, as a first approximation, on a percental basis (1891, 1908). A number of authors have followed Minot in this. It will be sufficient to cite Meyer (1914), Murray (1925), and Schmalhausen (1929), who considers the relative rate $\left(\frac{dy}{dt} \cdot \frac{1}{y}\right)$ as "die wahre Wachstumsgeschwindigkeit."

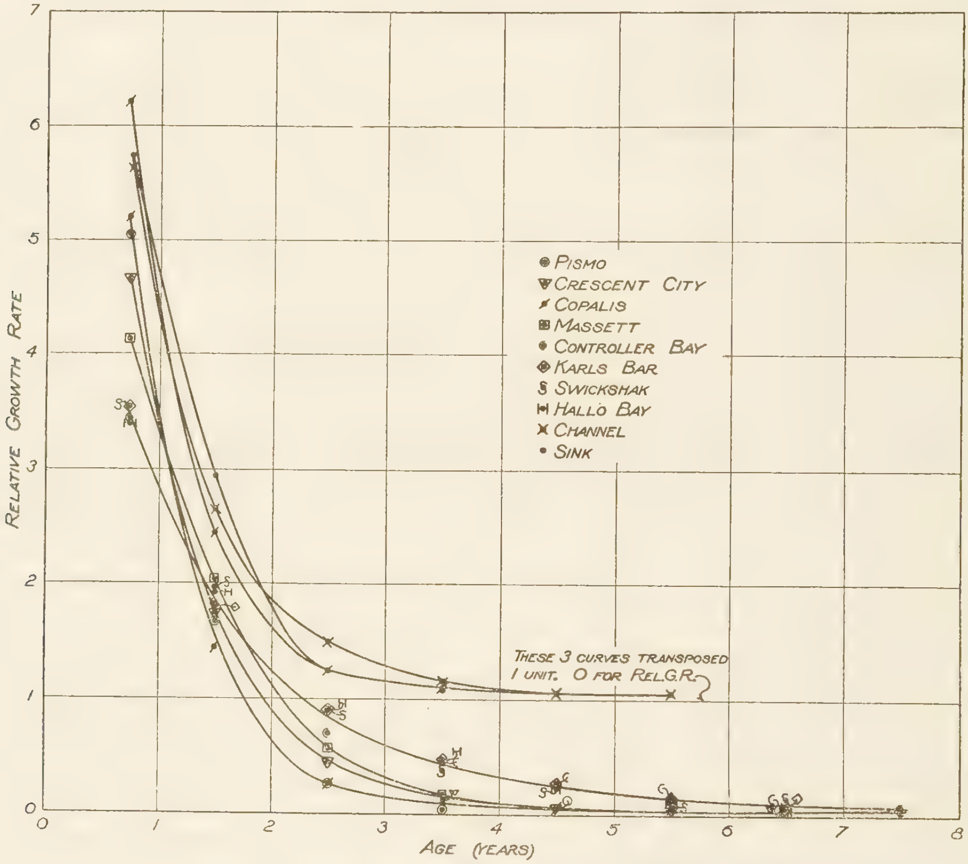

FIGURE 9.—Relative growth rate of clams from 10 localities plotted on age

If, following the above investigators, we consider the relative rate, the clams show the most rapid growth at the youngest age for which we have data. An example will make this clear. On the Swickahak beach the gross growth in length during the first growing season is 0.38 centimeter, in the twelfth growing season 0.36 centimeter. If we consider these as absolute increments they are essentially the same, but as in the first case the growth is made from the egg with a diameter of about 0.01 centimeter and in the second from a clam already 12.25 centimeters long, the relative growths are approximately 340 and 2 per cent, and the growth during the first summer is 170 times as fast as in the twelfth.

The definition of rate is important not only in early growth but also at the time of inflection on the absolute growth curve. Is the inflection as significant as its universal presence in the absolute growth curve would indicate, or as negligible as its complete absence from the relative growth curve would suggest? Brody (1927) claims several points of significance for the inflection, namely: (1) Maximum velocity of growth, (2) age of puberty, (3) lowest specific mortality, (4) equivalence in age of different animals. It is true that the inflection represents the greatest gross increase for a unit of time, but, as we shall show later, this is a mathematical fact of no biological significance. In the growth curves of man and rat the inflection roughly corresponds with the age of puberty, but Brody also shows on the same page growth curves of eight other species in which the inflection does not correspond to puberty. In the clam the inflection occurs at lengths from 3.17 to 5.81 centimeters, whereas sexual maturity does not occur until a size of about 10 centimeters is reached. (Weymouth, McMillin, and Holmes, 1925.)

The age of the inflection in man is the age of lowest specific mortality; but, since mortality data on other animals are not available, this generalization relating the inflection with specific mortality is unwarranted. As a "point of reference for the determination of equivalence of age in different animals" the inflection is a convenient working basis, but this has no influence on its possible biological significance.

Robertson (1923) claims no biological significance for the inflection but looks upon it as dividing the growth curve into two portions which Brody has designated the "self-accelerating" and "self-inhibiting" phases. These terms imply that the specific growth activity of the protoplasm increases up to the time of the inflection and thereafter declines. But this is not true; as many authors from Minot to Schmalhausen have pointed out, the intensity of growth due to an increasing proportion of inactive material in the organism and other causes is continually decreasing, a condition clearly shown by the relative growth rate of the clam (fig. 9) which falls without detectable change through the period of inflection on the absolute curve. The occurrence of a maximum gross addition which does not represent "die wahre Wachstumsgeschwindigkeit" will be clear from a moment's analysis.

An animal growing at a constantly decreasing relative rate will, if starting at a rate initially very high, show for a time an increasing absolute rate, each increment being, as in ordinary compound interest, larger than the preceding. But the falling relative rate will after a time more than offset the increasing body size; and the total gains will slacken and, having passed through a maximum, finally become progressively less, thus showing an inflection in the absolute rate. Viewed in this light, the inflection becomes a mere mathematical consequence of the course of growth and not a point which a priori might correspond to any physiological stage.

A hypothetical illustration may show how an inflection results from a constantly decreasing growth rate. Table 6 shows the increase of a small principal at compound interest, the rate of which is initially very high but steadily decreasing. For a time the income (annual increments) will be larger each year, but there will come a time when interest rate is so reduced that the income becomes smaller each year. The income will then be comparable to the absolute growth rate, showing an increase to a maximum followed by a decrease; a graph of the principal will be comparable to an absolute growth curve and show an inflection.

Table 6.—*The increase of a principal at compound interest when the interest rate is decreasing by 20 per cent each unit of time*

Principal	Interest rate	Income	Principal	Interest rate	Income	Principal	Interest rate	Income	Principal	Interest rate	Income
	Per cent			*Per cent*			*Per cent*			*Per cent*	
$0.31	152.6	$0.47	$27.72	25.6	$7.10	$70.63	5.4	$3.80	$87.02	1.1	$0.96
.78	122.1	.95	34.82	20.5	[1] 7.14	74.43	4.3	3.21	87.98	.90	.79
1.74	97.7	1.71	41.96	16.4	6.88	77.64	3.4	2.67	88.77	.72	.64
3.45	78.1	2.69	48.84	13.1	6.41	80.31	2.8	2.21	89.41	.58	.52
6.15	62.5	3.85	55.25	10.5	5.80	82.52	2.2	1.81	89.92	.48	.43
10.00	50.0	5.00	61.05	8.4	5.13	84.33	1.8	1.48	90.35	.37	.33
15.00	40.0	6.00	66.18	6.7	4.45	85.81	1.4	1.21	90.68	.29	.26
21.00	32.0	6.72									

[1] Inflection.

We are thus forced to conclude that the significant biological aspects of growth are not adequately shown by the plot of absolute size on age. Such curves indicate a slow growth at those early ages when each unit of protoplasm is actually putting forth a maximum of energy in the construction of new tissue. They further represent the most rapid growth as occurring at the "inflection" whereas it has been shown above that an increasing body size and a decreasing growth rate per unit mass at this age make a maximum contribution of new tissue. Therefore, if we analyze gross growth into its capacity and intensity factors we find that the rate is constantly decreasing and that the inflection neither corresponds to a biological epoch nor represents a real quantitative landmark.

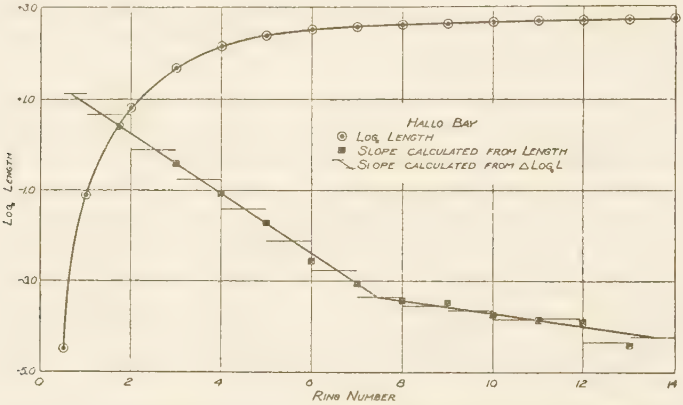

Figure 10.—Ratio diagram of growth of clams from Hallo Bay, Alaska, from larval stage to 14 years of age, with the slope of the growth rate calculated by two methods: Squares from the formula

$$\frac{1}{L} \cdot \frac{dL}{dt} = \frac{L_2 - L_1}{L_1} \cdot \frac{r \log_e r}{r-1} \text{ when } L = \text{length}$$

and

$$r = \frac{L_1(L_3 - L_1)}{L_3(L_2 - L_1)}$$

and horizontal lines from the graph of $\log_e (\Delta \log_e L)$

A GROWTH FORMULA BASED ON RELATIVE RATE

Having emphasized the importance of relative growth, we may consider it more in detail. If we examine the curves of relative growth rate (fig. 9), it will be noticed that the descent is regular, suggesting the logarithmic-exponential relation. A plot of the logarithm of the relative rate of growth on time, over the range of sizes for which we have data, closely approximates a straight line. (Fig. 10.) Therefore,

$$P_L = \frac{d \log L}{dt} = \text{relative growth rate}$$

$$\log P_L = a - kt$$

where a = initial relative growth
k = rate of decline
t = time.

$$\frac{d \log L}{dt} = e^{a-kt}$$

$$= Ae^{-kt} \qquad \text{where } A = e^a$$

$$\log L = \frac{A}{-k} e^{-kt} + b$$

$$= b - ce^{-kt} \qquad \text{where } c = \frac{A}{k}$$

$$L = e^{b-ce^{-kt}}$$

$$= Be^{-ce^{-kt}} \qquad \text{where } B = e^b$$

This formula, which is that of a Gompertz curve, fits the growth curve of the clams from all localities from the first winter to extreme old age when the observed values tend to be high. Although expressed in a different form, it contains the same idea as advocated by Minot who claimed that the percental growth decreased throughout life in the animals studied by him; namely, the guinea pig, rabbit, and man. To use his terminology we might say that the percental growth rate declines at a constant percental rate. This growth formula was developed in ignorance of the work of Wright and Davidson, the latter now associated with the writers. Wright suggested (1926) and Davidson developed and later applied with Wright's assistance, a formula essentially the same as that here given to the growth of cattle (1928). This is the first case, however, in which it has been applied to a growth curve including an inflection.

DIFFERENCES OF GROWTH IN DIFFERENT LOCALITIES

We have presented the general features common to all our growth curves which, as we have stated above, are representative of growth in 10 localities ranging from Pismo, Calif., to Hallo Bay, Alaska—a distance of over 2,500 miles along the Pacific coast and 25 degrees of latitude. It remains to consider the differences in growth of clams as influenced by the great differences of environment encountered in this unusually wide range.

To analyze these differences, we selected for comparison a large number of constants derived from the growth curves. These we have studied by means of scatter diagrams and in many cases have calculated the coefficients of correlation between selected constants. As a result we have chosen five constants as the most significant for comparison and have presented their values in Table 7 and the coefficients of correlation in Figure 11.

As representative of age and length the maxima, as defined above, were selected as most significant. The growth rate, while a single feature, shows such characteristic relation between its initial and its later course that two constants were necessary to represent it. Those selected were the initial relative growth rate and the rate at two years. These constants have been compared with the geographical position as represented by the distance in statute miles along the coast from Pismo.

TABLE 7.—*Growth constants of Siliqua patula for the localities considered*

	Pismo	Crescent City	Channel	Sink	Copalis	Massett	Controller Bay	Karls Bar	Swickshak	Hallo Bay
Latitude	35° 11′	41° 45′	46° 58′	46° 58′	46° 58′	53° 20′	60°	60° 27′	58° 5′	58° 5′
Distance from Pismo miles	0	500	860	860	860	1,380	2,040	2,105	2,405	2,425
5 per cent survival age[1] years	4.40	7.90	7.00	7.00	8.85	9.55	11.00	12.05	13.40	15.65
5 per cent survival length centimeters	12.05	13.40	11.40	12.00	14.40	13.70	13.00	15.95	16.00	15.70
Average growth centimeters	2.74	1.69	1.63	1.72	1.63	1.43	1.18	1.32	1.19	1.00
Initial relative growth rate	5.05	4.67	4.59	4.69	5.21	4.14	3.43	3.53	3.53	3.39
Relative growth rate, 2 years	0.25	0.43	0.49	0.23	0.23	0.56	0.68	0.90	0.85	0.88

[1] Given as ring number. To calculate actual age subtract one-half year.

It is obvious that a satisfactory analysis is impossible at present. The physico-chemical factors represented by the environment are imperfectly known for even the most studied points on the Pacific coast; and for many of our localities we have no information whatever as to temperature, salinity, hydrogen-ion concentration, plankton, or any other of the agencies known to influence physiological processes. We may safely infer that the temperatures on the southern beds are higher and the season of higher temperatures is longer than in the north, but we can not put this into quantitative form.

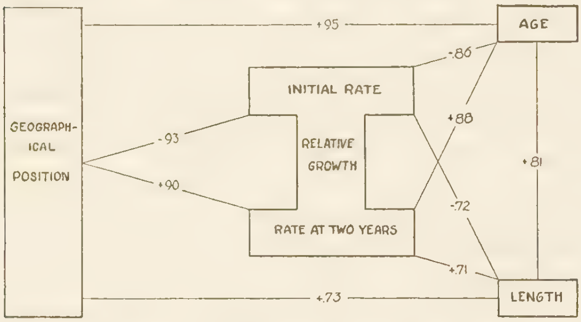

FIGURE 11.—Diagram of the five constants derived from growth curves with coefficients of correlation for each pair

The striking fact that many features of growth show such high correlation with the group of environmental features indicates that a satisfactory knowledge would reveal important laws of growth. For the present we can only record the suggestive observed relations which can not yet be analyzed.

The correlations obtained are given in Figure 11. For biological data these correlations are strikingly high, ranging from 0.71 to 0.95. The highest of these is between age and geographical positions in the sense that clams from the northern beds show the longest life or the lowest mortality. The next highest is the negative correlation between the initial growth rate and that at two years. Since these constants are two measures of the same thing, a close relation would be expected and the figure indicates that a high relative growth rate in early life is followed by a low growth rate in later life and vice versa.

In consequence, the correlations of the early and late growth rates with other constants show similar values but have opposite signs. The highest correlation of relative growth rate is with geographical location. The highest initial and lowest final values are found at Pismo, the southernmost locality. The next highest correlations are between relative growth rate and age. A low initial rate and high later rate are associated with long life.

The correlations of length with the other factors are the lowest. Large size is associated with great age, northern habitat, low early and high later relative growth rates. This lower correlation apparently reflects the fact that there is a lower percental variability in length than in any of the other factors.

To summarize, we may say that the complex of environmental features on the southern beds produces a more rapid initial relative growth rate which more rapidly falls to a lower final value, and that the clams reach a smaller final length and have a shorter life span than on the northern beds.

That these differing types of growth characteristic of the different localities are significant is indicated by their occurence in other cases. An example is furnished by the comparison of the growth of the two sexes at Hallo Bay, Alaska, where, as stated, slight sexual differences in size were observed. An inspection of Figure 4 will show that the females grow more rapidly at first, but that by the third or fourth year the more sustained growth of the males has placed them in the lead, and that they reach a greater final length and outlive the females on the average by more than a year. Chamberlain obtained for one species of fresh-water mussel a sexual difference in growth similar to that just described (1931). The results from other species of lamellibranchs are concordant. Thus in *Cardium* the differences of growth with latitude appear to parallel those found in the razor clam (Weymouth and Thompson, 1931). It is not here possible to examine other groups but recent work on the life history of the striped bass in California by Scofield[3] has shown a difference in growth between the sexes essentially similar to that in the razor clam.

Although the case is not comparable in detail, the findings of Gray (1928), who reared the eggs of *Salmo fario* at different temperatures, is interesting. Those developing at 15° C. grew far more rapidly but did not reach as great a weight as did those growing at 5° C. Gray points out that the yolk available for the metabolism of the embryo is limited, and must serve for both maintenance and growth. At the higher temperatures the life processes are pitched at a higher level and the fraction consumed in maintenance is greater, that available for growth is therefore less, hence the smaller size. Although there is no similar limitation of food material in the case of the clam, the observations are suggestive.

BIOLOGICAL FINDINGS AND THEIR BEARING ON FISHERY REGULATIONS

On the basis of the data presented in this and previous reports on the razor clam (McMillin, 1924, 1925, 1927, 1928; Weymouth, McMillin, and Holmes, 1925; Weymouth, McMillin, and Rich, 1931), the more significant biological findings may be summarized and their bearing on the question of fishery regulations pointed out.

BIOLOGICAL FINDINGS

These investigations have extended the applicability of the ring method of age determination to the razor clam. Work now in press (Weymouth and Thompson, 1931), has shown that the same relations hold for the cockle (*Cardium corbis*) and Chamberlain[4] has successfully applied the method to the fresh-water mussel (*Lampsilis*). There can be little doubt, therefore, that the ring method is of general validity for lamellibranchs and that in it we have a tool of great usefulness for the study of growth.

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[3] Manuscript in press. California Fish and Game Commission.

[4] Thesis, Stanford University.

These studies have furnished what is doubtless the largest body of invertebrate growth data as yet available. Since these growth data are uniquely regular it has permitted an analysis of certain features of growth not hitherto possible. This analysis has substantiated and extended the earlier findings of Minot, making possible a valuable mathematical formulation of the course of growth.

Many problems of growth and its relation to variability and longevity, as yet unsolved, may be confidently attacked by this method, and data are already at hand or will be obtained incidentally in the surveys hereafter proposed.

RAZOR-CLAM FISHERY AND ITS REGULATION

(*a*) Neither artificial propagation nor culture are feasible. Proper protective measures can maintain the present beds, but no extension can be expected. The forms suitable for "farming" on the Pacific coast are the oyster and soft-shelled clam (*Mya*). These may readily be extended to many bays now unproductive. The razor clam should and can be protected; it has, however, already spread to all suitable locations.

(*b*) With the knowledge of the rate of growth, the length of life, and the set at different latitudes now available, we may predict the resistance of various beds to commercial fishing. In the south the rate of growth is rapid; the life, short; and the set, heavy. In the north the rate is low; the life, long; and the set, light. Balancing these factors, the Washington beaches are undoubtedly the most resistant—a conclusion borne out by the history of the commercial fishery.

(*c*) *Evidences of overfishing.*—The validity of the method of age determination developed by the senior author is now well established. By its use the composition of the commercial catch may readily be ascertained. A fall in the relative abundance of the older age groups (with due allowance for dominant age classes) is the best evidence of danger from too intense fishing. This method of analysis has been applied by one of us (McMillin, 1925, 1927, 1928) to the Washington fishery, with such striking evidence of depletion that the State has finally passed protective measures including a size limit of 3½ inches and a bag limit of 3 dozen for the unlicensed digger. The fishery at Cordova is being followed by the same method and the size limit of 4½ inches set as a result of the first survey (Weymouth, McMillin, and Holmes, 1925) is proving an efficient protection. Measured areas, marked with permanent stakes, may be dug on successive days, and the same or similar areas examined each year. These areas are often avoided by the commercial diggers and are, therefore, not a completely satisfactory index of the general conditions of the beds, or contours of bottom may so change that successive records are not comparable. Nevertheless this method gives valuable supplementary evidence of the trend of the fishery.

(*d*) *Methods of protection.*—The protective measures available are closed seasons, closed areas, bag limits, and size limits. Additional experience in the application of these measures have supported the arguments advanced in a previous report (Weymouth, McMillin, and Holmes, 1925) in favor of the size limit. A bag limit has been set on the noncommercial digger for the Washington beaches, but has never been advocated for commercial operations. The closing of areas to digging would appear a useful method of protection, but experience has not proved it feasible. In the first place, the nature of the razor-clam beaches makes them difficult to post and police. Accurate description is often impossible because of absence of landmarks and the constant changing of the bars. This results in confusion and friction between wardens and diggers. The closed season so widely used elsewhere as a protective measure, if used alone, simply results in a shift of the time of intense digging and a concentration of effort in a shorter period. The total catch is not reduced, but its rapid handling leads to greater waste. This has been well illustrated on the Washington beaches.

The minimum size limit insures a reserve of breeding animals, and protects the clam at a time when it is increasing most rapidly in weight and therefore in economic value. The wastefulness of unrestricted digging has been emphasized by one of us (McMillin, 1927, 1928) in the case of the Washington beaches where, in 1928, the young not yet of spawning age constituted 42.5 per cent of the catch. Only the remarkable resilience of the clam populations on these beaches resulting from the heavy set and rapid growth have saved them from commercial extinction. Even with the protection now afforded these younger clams it will require time to rebuild the fishery. It was feared when the size limit was first proposed that its enforcement would be difficult, but this has not proved to be the case. The small clams, which are largely wasted in the canning operations because of the difficulty of cleaning them, are not wanted by the canners who have cooperated in enforcing the regulations. The size limit results in the practical closure of depleted areas. Beds which will not yield enough legal sized clams to repay the digger are carefully avoided.

(*e*) *Future work.*—It is recommended that surveys be made at least biennially of those regions where the razor-clam fishery is well developed to furnish material from which the age composition of the commercial catch may be found. If new regions are opened, these should be sampled at once in order that their subsequent history may be followed. Such surveys will show overfishing and permit the intelligent adjustment of regulations before conditions become acute and necessitate drastic action.

SUMMARY

The present paper is a continuation of previous studies of the Pacific razor clam undertaken for the Bureau of Fisheries.

The relationships of the most abundant and only commercially important species, *Siliqua patula*, are considered.

The variability, mortality, and sexual differences within the species are discussed.

Data on the growth of clams from 10 localities are presented, together with a discussion of methods employed and localities considered. Similarities shown by the growth data and the conception of growth to which they lead is given, and a critical examination of the graphic representation and terminology follows. The differences exhibited by the various localities are discussed.

Among legal restrictions on the fishery the importance of the size limit is again emphasized.

TABLE 8.—*Lengths of Siliqua patula at various localities*

Ring No.	Median		P_{10}		P_{90}		Number of specimens	D
	Length	P. E.	Length	P. E.	Length	P. E.		
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*		
PISMO								
1	1.73	±0.024	1.27	±0.018	2.39	±0.030	272	1.12
2	9.07	±0.045	7.78	±0.083	9.80	±0.032	262	2.02
3	11.63	±0.016	10.51	±0.120	12.34	±0.050	153	1.83
4	12.10	±0.063	11.42	±0.038	12.66	±0.113	31	1.24
5	12.68	------	------	------	------	------	5	------
CRESCENT CITY								
1	1.19	±0.060	0.45	±0.023	2.26	±0.058	169	1.81
2	6.75	±0.093	5.21	±0.058	9.14	±0.085	178	3.93
3	10.35	±0.045	9.30	±0.070	11.93	±0.072	170	2.03
4	11.81	±0.046	11.11	±0.039	12.60	±0.059	160	1.49
5	12.58	±0.040	11.75	±0.066	13.29	±0.044	144	1.54
6	13.03	±0.040	12.32	±0.055	13.83	±0.063	110	1.51
7	13.32	±0.083	12.26	±0.150	14.16	±0.187	38	1.90
8	[1] 13.84	------	------	------	------	------	8	------
9	[1] 13.51	------	------	------	------	------	1	------
CHANNEL (COPALIS)								
1	1.09	±0.055	0.49	±0.016	1.89	±0.029	167	1.40
2	5.59	±0.103	3.18	±0.111	7.66	±0.080	189	4.48
3	9.10	±0.100	6.49	±0.055	10.81	±0.067	177	4.32
4	10.54	±0.164	9.06	±0.112	11.48	±0.064	122	2.42
5	11.08	±0.086	10.19	±0.104	12.04	±0.052	59	1.85
6	11.50	±0.108	10.83	±0.097	12.28	±0.048	23	1.45
7	[1] 11.89	------	------	------	------	------	8	------
8	[1] 11.89	------	------	------	------	------	2	------
SINK (COPALIS)								
1	1.21	±0.085	0.63	±0.017	2.12	±0.087	101	1.49
2	8.35	±0.055	6.84	±0.428	8.97	±0.025	112	2.13
3	[2] 10.49	±0.040	9.31	±0.213	11.14	±0.106	111	1.83
4	11.18	±0.057	10.33	------	[2] 11.94	------	102	1.70
5	11.78	±0.063	10.79	------	[2] 12.48	------	88	1.69
6	[2] 11.96	±0.050	[2] 11.04	------	[2] 12.68	------	34	1.74
7	[1] 12.70	------	------	------	------	------	3	------
8	[1] 13.40	------	------	------	------	------	2	------
COPALIS								
1	2.04	±0.016	1.11	±0.040	2.98	±0.055	468	1.87
2	8.61	±0.043	6.37	±0.079	9.76	±0.023	457	3.39
3	10.87	±0.026	10.08	±0.038	11.72	±0.024	424	1.64
4	12.04	±0.020	11.40	±0.036	12.62	±0.020	388	1.28
5	12.81	±0.008	12.12	±0.046	13.48	±0.029	330	1.36
6	13.40	±0.020	12.85	±0.043	14.02	±0.013	250	1.17
7	13.84	±0.028	13.28	±0.053	14.48	±0.035	172	1.20
8	14.19	±0.050	13.70	±0.121	14.90	±0.052	80	1.20
9	14.50	±0.095	13.78	------	15.12	------	18	1.34
MASSETT, B. C.								
1	0.70	±0.016	0.40	±0.017	1.88	±0.092	186	1.48
2	5.35	±0.159	3.32	±0.064	8.03	±0.096	201	4.71
3	9.35	±0.067	7.45	±0.094	10.51	±0.081	195	3.06
4	10.97	±0.055	9.88	±0.062	11.97	±0.093	190	2.09
5	11.78	±0.041	11.03	±0.049	12.60	±0.054	146	1.57
6	12.58	±0.060	11.77	±0.071	13.54	±0.107	112	1.80
7	13.27	±0.035	12.57	±0.200	14.07	±0.080	97	1.50
8	13.58	±0.034	12.68	±0.110	14.16	±0.083	67	1.48
9	13.69	±0.048	12.67	±0.067	14.45	±0.101	25	------
10	[1] 14.16	------	------	------	------	------	4	------

[1] Mean.

[2] Graphic.

TABLE 8.—*Lengths of Siliqua patula at various localities*—Continued

Ring No.	Median		P_{10}		P_{90}		Number of specimens	D
	Length	P. E.	Length	P. E.	Length	P. E.		
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*		
CONTROLLER BAY								
1	0.34	±0.037	0.18	±0.044	0.53	±0.034	58	0.35
2	[2] 2.12	±0.067	1.23	±0.036	2.83	±0.032	80	1.60
3	4.18	±0.062	3.10	±0.072	5.10	±0.062	80	2.00
4	6.52	±0.067	5.30	±0.091	7.84	±0.052	80	2.54
5	8.45	±0.046	7.39	±0.180	9.46	±0.072	79	2.07
6	9.71	±0.064	8.71	±0.034	10.75	±0.115	72	2.04
7	10.51	±0.064	9.55	±0.102	11.71	±0.076	58	2.16
8	11.25	±0.042	11.19	±0.126	12.31	±0.084	39	1.14
9	[2] 11.90						13	
10	[1] 12.60						6	
11	[1] 13.00						5	
12	[1] 13.28						3	
13	[1] 13.51						1	
KARL BAR (CORDOVA)								
1	0.38	±0.013	0.23	±0.014	0.58	±0.032	123	0.35
2	2.43	±0.037	1.82	±0.049	3.05	±0.041	148	1.23
3	5.49	±0.055	4.30	±0.099	6.80	±0.083	150	2.50
4	8.57	±0.092	7.30	±0.050	9.86	±0.099	150	2.56
5	10.92	±0.055	9.50	±0.055	12.24	±0.082	149	2.74
6	12.66	±0.055	11.67	±0.121	13.49	±0.040	146	1.82
7	13.78	±0.039	12.95	±0.078	14.54	±0.059	135	1.59
8	14.52	±0.049	13.58	±0.078	15.27	±0.052	133	1.69
9	15.03	±0.056	14.21	±0.062	15.77	±0.053	84	1.56
10	15.43	±0.071	14.74	±0.051	16.00	±0.064	37	1.26
11	15.63	±0.063					22	
12	15.95	±0.067					15	
13	16.05						9	
14	15.90						5	
15	[1] 15.95						2	
16	[1] 16.15						2	
17	[1] 16.25						2	
18	[1] 16.40						2	
SWICKSHAK BEACH								
1	0.38	±0.010	0.24	±0.007	0.76	±0.026	238	0.52
2	2.73	±0.028	1.94	±0.035	3.69	±0.041	545	1.75
3	6.41	±0.076	4.70	±0.068	7.81	±0.080	275	3.11
4	9.28	±0.060	8.12	±0.051	10.94	±0.069	254	2.82
5	11.49	±0.058	10.30	±0.077	12.68	±0.065	239	2.38
6	12.74	±0.048	11.92	±0.048	13.76	±0.083	228	1.84
7	13.70	±0.040	12.74	±0.044	14.51	±0.062	218	1.77
8	14.19	±0.045	13.27	±0.072	15.11	±0.087	204	1.84
9	14.63	±0.051	13.67	±0.060	15.60	±0.052	177	1.93
10	14.94	±0.064	13.94	±0.065	15.93	±0.063	166	1.99
11	15.25	±0.054	14.29	±0.086	16.28	±0.055	127	1.99
12	15.61	±0.118	14.53	±0.082	16.61	±0.089	77	2.08
13	16.12	±0.046	15.19	±0.071	16.78	±0.033	17	1.59
14	[1] 15.96						5	
15	[1] 16.72						1	
HALLO BAY								
1	0.34	±0.012	0.23	±0.022	0.59	±0.007	91	0.36
2	2.26	±0.048	1.11	±0.032	3.28	±0.050	226	2.17
3	5.42	±0.114	3.44	±0.047	7.56	±0.087	229	4.12
4	8.60	±0.138	6.67	±0.087	10.61	±0.087	229	3.97
5	10.96	±0.078	9.42	±0.059	12.49	±0.043	228	3.07
6	12.37	±0.049	11.13	±0.068	13.45	±0.044	227	2.32
7	13.17	±0.050	12.08	±0.080	14.04	±0.043	211	1.96
8	13.65	±0.045	12.72	±0.048	14.53	±0.056	192	1.81
9	14.06	±0.041	13.28	±0.056	14.88	±0.042	182	1.60
10	14.44	±0.045	13.63	±0.053	15.22	±0.048	172	1.59
11	14.75	±0.048	13.94	±0.053	15.51	±0.071	138	1.57
12	15.08	±0.063	14.30	±0.047	15.80	±0.061	111	1.50
13	15.38	±0.056	14.58	±0.063	16.07	±0.063	77	1.49
14	15.50	±0.081	14.71	±0.080	16.46	±0.147	52	1.75
15	15.80	±0.095	14.87	±0.211	16.73	±0.211	27	1.86
16	[1] 15.61						7	
17	[1] 15.74						4	
18	[1] 16.31						3	
19	[1] 16.74						2	

[1] Mean.

[2] Graphic.

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NATURAL HISTORY OF THE BAY SCALLOP[1]

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INTRODUCTION

The bay scallop, *Pecten irradians*,[2] is one of the few commercial, edible bivalves of our Atlantic coast. In North Carolina, where it is of considerable national and very great local importance, it had received almost no scientific study previous to these investigations. Accordingly an investigation was undertaken at the United States Bureau of Fisheries station, Beaufort, N. C., which is in the heart of the scallop-producing area in this State. Work was begun in the summer of 1925 and continued into 1928.[3]

Effort was concentrated on those aspects of life history which it was thought would yield knowledge of greatest usefulness for conservation. However, during certain periods, time was found for anatomical and other studies. Because of the economic importance of the form, its many points of interest, and the lack of a connected available account with a detailed description of the adult, the attempt has been made to make this account of the bay scallop reasonably complete and well rounded.

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[1] Submitted to the faculty of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. Submitted for publication Nov. 13,1929.

[2] Also known as *Pecten gibbus*. See discussion under "Classification and relationship."

[3] I wish to thank Capt. John A. Nelson, commissioner, and others of the division of commercial fisheries, Department of Conservation and Development, North Carolina, for much helpful service during these investigations.

ECONOMIC IMPORTANCE

The bay scallop is an article of commerce in Massachusetts (the leading producer), Rhode Island, New York, Virginia, North Carolina, and, according to the Bureau of Fisheries latest statistics, Florida. In commercial value it ranks third among American mollusks, after the oyster and the hard clam, Venus. The accompanying table (Table 1) is compiled from data furnished by the division of fishery industries, and does not include an item of something over $11,000 for a closely allied but not identical west coast scallop. The large and commercially important giant or sea scallop of the Atlantic is also largely if not completely excluded. For comparison there are included Ingersoll's estimates for 1880 (Ingersoll, 1887).

Table 1.—*Quantities and values of bay scallops at early and recent dates*

State	Catch for 1880		Catch for most recent years[1]	
	Pounds	Value	Pounds	Value
Massachusetts	111, 600	$44, 640	1, 235, 304	$548, 348
Rhode Island	180, 000	72, 000	42, 870	28, 588
New York	288, 467	115, 387	299, 892	92, 253
Virginia			360, 732	74, 272
North Carolina	67, 500	27, 000	1, 394, 124	125, 845
Florida			14, 100	5, 000
Total	647, 567	259, 027	3, 347, 022	874, 306

[1] Statistics have not been collected annually in each State for any one recent year, so the statistics for the latest year are taken in each instance as follows: Massachusetts, Rhode Island, North Carolina, and Florida, 1928; New York, 1926; and Virginia, 1925.

In North Carolina, because it is limited to a small area with a meager population and because it offers the only opportunity for winter work for quite a proportion of the people of the scalloping area, the scallop fishery is of very great local importance.

LITERATURE

The old, colloquial name *Pecten* (which means comb) appears in pre-Linnæan scientific writings and was used by Linnæus although not formally adopted by that great naturalist (see Dall, 1898), who described numerous species of scallops under the generic name of *Ostrea*. Chiefly because of the adoption of its shell as a symbol of holy pilgrimage and its appearance in coats of arms, references to the scallop are frequent not only in zoological but also in popular literature, especially verse (see Ingersoll, 1887).

In general the numerous writings consulted will be referred to in later sections according to the subjects with which they deal. However, it may be worth while to note a few of the earlier works and some most used in the study on which this paper is based.

Poli (1795) described or figured the eyes, tentacles, gills, palps, fringed lips, foot, adductor muscle, kidneys, and rectum. His figure showing arrangement and appearance of soft parts of *Pecten jacobaeus* is very good and is still used (Pelseneer, 1906).

Another early investigator whose work is of notable interest is Garner, who described and figured the ocelli and nervous system (Garner, 1837, read 1834). He studied the circulatory system by means of injections (Garner, 1838–39, 1841) and attributed the great size of the adductor muscle to its use in clapping the shell in the swimming process. He suggested the importance of the gills for classification and discovered (see Kellogg, 1892) that the sexual products are discharged through the kidney.

Modern studies which have been especially useful are the account of the scallop fishery by Ingersoll (1887) in The Fishery Industries of the United States; papers by Jackson (1890) and Kellogg (1892 et. seq.); the Memoirs by Drew (1906) and Dakin (1909); and the account by Belding (1910).

CLASSIFICATION AND RELATIONSHIP

Among the schemes of classification of lamellibranchs, that employing the structure of the gills is the simplest and seems to be gaining most favor among students of recent forms. The possibility of such a scheme was suggested by Lankester in 1883. Development is due to various workers, notably Pelseneer, Menegaux, and Ridewood. Pelseneer's classification of orders (1906) is essentially that of Ridewood (1903); but with certain order names previously given by Pelseneer used instead of the new names proposed by Ridewood, and with the Septibranchs retained as an order. Under this scheme forms with flat, platelike, unreflected gill filaments (Protobranchia) are regarded as most primitive; those with reflected filaments held together in lamellae by interlocking cilia (Filibranchia) as higher in advancement; those with reflected filaments joined one with the other by vascular connection (Eulamellibranchia) as having attained the highest development; and the Septibranchs as being forms with degenerate gills.

In such a classification the scallops belong with the Filibranchia but evidently are close to the Eulamellibranchia, because vascular filamentary connections are found in the giant or sea scallop (*Pecten tenuicostatus* Mighels, as employed by Drew but, according to Dr. Paul Bartsch, in correspondence, *Pecten grandis* Solander).

Cooke (1895) and also Parker and Haswell (1897) employ a somewhat different classification with an intermediate order, the Pseudolemellibranchiata, in which are placed the oysters and the scallops with a few others. Although, as previously noted, the intermediate position for the scallop is indicated, the oysters would seem clearly to belong with the Eulamellibranchiata, and it may be questioned whether this intermediate order does not increase rather than decrease the difficulties.

In its main outline, classification according to the gill structure has the advantage of being a simple, logical, readily understandable one, which presents a reasonable interpretation of phylogenetic relationship. It seems the most useful scheme developed. Undoubtedly the understandable logic of the main outline of classification according to gill structure has had much to do with its favorable reception and may have unduly influenced zoologists. In the classification which Dall (1895) introduced after many years of study, the attempt is made to take into consideration all structural evidence. In this classification Pectinacea is constituted quite differently and placed with groups including Solenomya, Ostrea, and others in the order Teleodesmacea. The class is termed Pelecypoda. See also Rice (1900, 1908) and Verrill (1899).

The bay scallop almost universally is placed in the genus Pecten, but as to the species there is some difference of opinion and usage. Dall (1898) placed what I term the bay scallop—ranging from Massachusetts to the Gulf of Mexico and even to Brazil—in one species. Davenport (1903), largely as a result of "ray counts," finds the Beaufort (N. C.,) scallops very close to those of Cold Spring Harbor, N. Y., and noticeably different from those of Tampa, Fla., but admits the possibility of intergrades. The modal number of shell rays or ribs is given as follows: Cold Spring Harbor, 17; Beaufort, 17; and Tampa, 20. It is not clear from the context how the number for Beaufort was obtained, although abundant data for the other points are given. I made a count of rays on Beaufort shells and found 18 most prevalent, but with 17 nearly as numerous. The extremes in this count, which included 150 right valves and 46 left valves, were 16 and 20. (See Table 2.) The number was determined by counting the inner grooves much as was done by Davenport, except that two half grooves were not taken to equal one full groove. Jacot (1921), presumably counting the outer ribs instead of the inner grooves, found two subspecies, one commonly with 19 ribs (18–20) the other with 20 (19–22).

Table 2.—*Counts of rays or ribs on scallop shells from Beaufort and vicinity*

	16 rays	17 rays	18 rays	19 rays	20 rays
Right valve	10	52	68	16	4
Left valve	4	13	21	9	1
Total	14	65	89	25	5

Like Davenport, I hesitate to pass on the question of species. I accept Dall's decision in favor of one species for our Atlantic coast and consider that the available morphological evidence is strongly in favor of the view that the bay scallops, at least of the important commercial centers (North Carolina, New York, Virginia, and Massachusetts) are specifically the same. In Bulletin No. 37 Dall (1889) employed the name *Pecten irradians* Lamarck. In the "Tertiary Fauna of Florida" (Dall, 1898), on the ground of integradation with the Jamaican scallop which Linnæus described as *Ostrea gibba*, he employs the name *Pecten gibbus* Linné with *irradians* as a subspecies. Kellogg, Drew, and Belding use *P. irradians*. In correspondence, Dr. Paul Bartsch expressed himself in favor of that name, in the belief that our scallop is distinct from that of Jamaica; and Dr. H. A. Pilsbry favors it if the binomial is used. The name *Pecten irradians* Lamarck is here employed.

Although on morphological evidence the Beaufort and Massachusetts scallops are held to belong to one species, it is perhaps worthy of note in this connection that in one important biological aspect—spawning—the Beaufort scallops differ markedly from those of northern waters. The Beaufort scallops spawn principally in the fall when water temperature is falling; the others, according to Risser (1901) and Belding (1910), in the spring or early summer when the temperature is rising.

HABITAT AND DISTRIBUTION

According to Dall (1889) the range of *Pecten irradians* is from Nova Scotia to Tampa, Fla. Later (1898) he concluded that West Indian scallops were specifically the same as those of our Atlantic coast and that the species extended to Brazil. Kellogg (1910) reports it from the vicinity of the Chandeleur Islands in the Gulf of Mexico, and gives the range as Cape Cod to Texas. Belding (1910) states that it occurs from Massachusetts Bay to the Gulf of Mexico, but adds that a few are reported to be found in some of the warm bays of the Maine coast. Ingersoll (1887) found it rare or local "north of that great dividing point"—Cape Cod. In important commercial abundance it occurs so far north as Cape Cod and at least as far south as

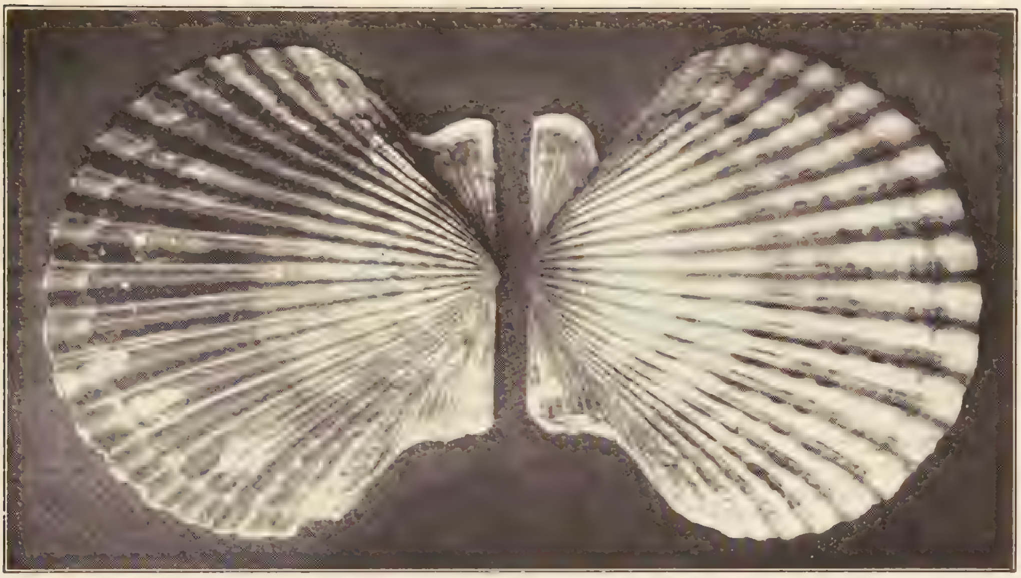

FIGURE 1.—Shell of bay scallop. Exterior view of left and right valves

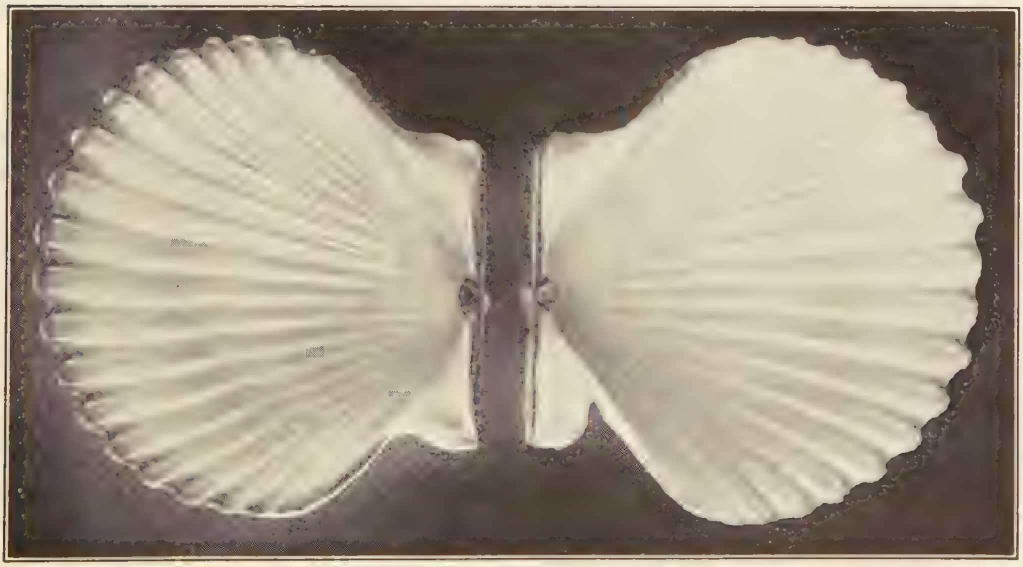

FIGURE 2.—Interior view of left and right valves. The lower or right valve, shown at right, is marked by the byssal notch

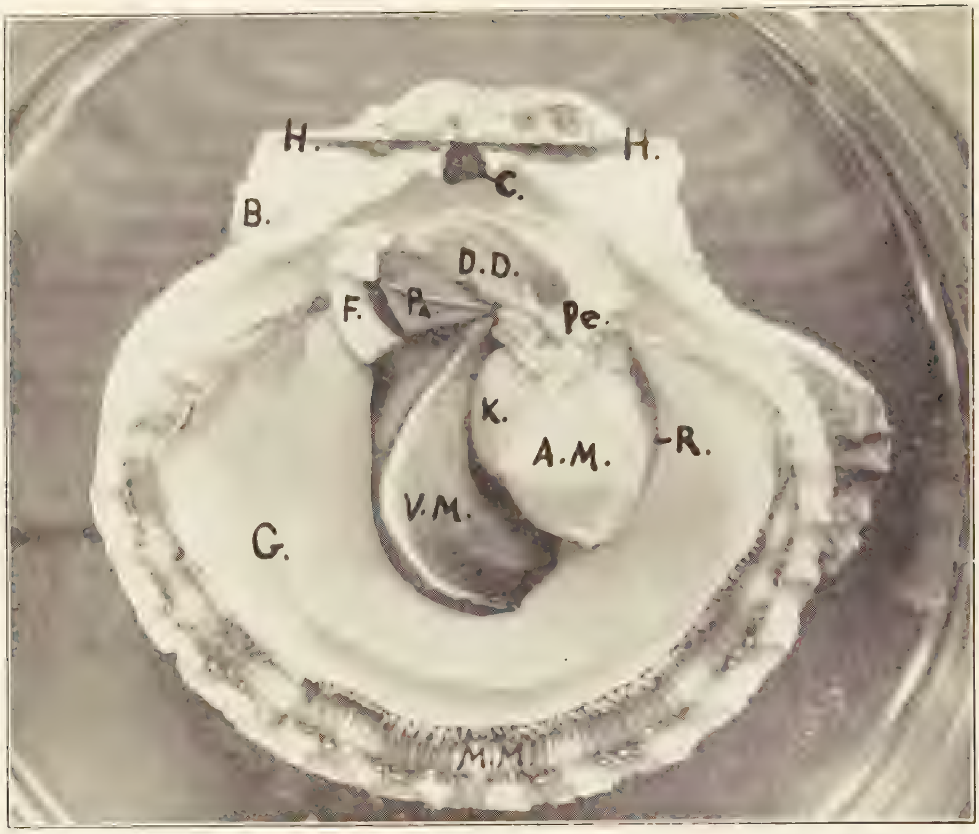

Figure 3.—Bay scallop lying on its right side, with left valve, left gill, and most of left mantle lobe removed. *A. M.*, adductor muscle; *B.*, byssal notch (overgrown by *Ostrea equestris*); *C*, cartilage; *D. D.*, digestive diverticula overlying stomach; *F.*, foot; *G.*, gill: H., hinge; K., execretory organ or kidney; *M. M.*, mantle margin with eyes and sensory tentacles along outer edge and guard tentacles along inner edge; *Pa.*, palps; *Pe.*, pericardium; *R.*, rectum; *V. M.*, visceral mass

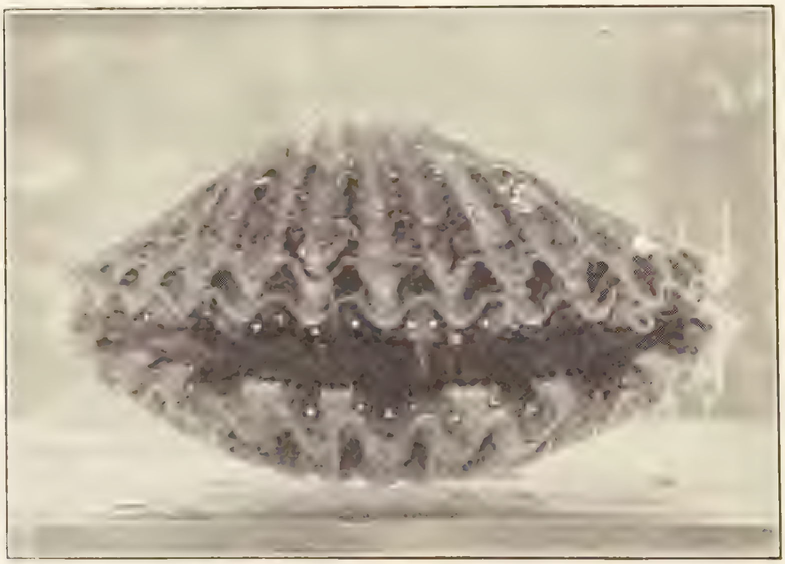

Figure 4.—Unretouched photograph showing sensory tentacles somewhat extended, eyes with their centers gleaming in the sun light, the flap of the lower mantle lobe, and the guard tentacles of both flaps

Bogue Sound, N. C. A small commercial catch is recorded for Florida in 1928. Areas famous for the abundance (past or present) of scallops are: The south shore of Cape Cod and Buzzards Bay, Mass.; Greenwich Bay, R. I.; Long Island Sound, particularly sections of the Connecticut shore (unproductive since an early date); Peconic Bay, Long Island, N. Y.; and Bogue Sound, Core Sound, and Beaufort Harbor in North Carolina. In suitable coastal areas between Long Island and North Carolina it occurs, or has occurred, sometimes in commercial numbers. Of recent years important catches have been taken near Chincoteague, Va.

The range in depth is from that of flats with only a foot or so of water over them at ordinary low water (bare at extreme low water) to as much as 60 feet (Belding, 1910). In North Carolina, where the sounds are very shallow, comparatively few scallops are found at a depth of much more than 6 feet.

As its name implies, the bay scallop is principally an inhabitant of inclosed waters—bays, harbors, estuaries, and sounds. These may be either of ocean saltness or decidedly brackish. Belding (1910) states that the density (temperature not given) may be as little as 1.010. In North Carolina scallops occur in commercial abundance in water ordinarily ranging in salinity from about 20 parts per mille (possibly decidedly less for brief periods) to 38 parts per mille. There may be a strong tide, a moderate tide, or almost none. Ordinarily scallops occur amid a growth of eelgrass (Zostera) or other vegetation. This plant growth may be long and heavy or short and sparse. The type of bottom varies from soft mud to hard sand (but not shifting sand).

ORGANIZATION AND MODE OF LIFE

SHELL

The general outline and appearance of the shell of an adult scallop are shown in accompanying photographic illustrations. (Figs. 1 and 2.) In addition, Figure 5*a* illustrates the cross sectional shape of the ribs and Figure 5*b* that of the shell, through center of umbo, fossette, and central rib. The umbos are straight (nonspiral) and approximate and directed at right angles to the hinge, near the center of which they are located. The central position of umbos relative to the anterior and posterior portions has, in an allied species, led Dakin (1909) to term the shell equilateral, although there are small posterio-anterior differences which strictly make it inequilateral. The deeper cupping of the lower right valve makes the shell inequivalve, a condition found in comparatively few lamellibranchs and doubtless an adaption to a lateral position in life. The deep byssal notch in the right valve is anterior, and the fossette or cartilage box points somewhat anteriorly. The adductor muscle impression is posterior but very faint, as is also the pallial line (without sinus). The shapes of the auricular regions or "ears" are well shown in the photographs. (Figs. 1 and 2.) The posterior auricular margin is slightly obtuse, the anterior reflected.

The long, thin external ligament (the ligament proper) extends the length of the hinge either side of the umbos (the type termed by Dall (1895) amphidetic) and holds the valves together along the hinge line. The cartilage (or so-called internal ligament, the resilium of Dall), roughly pyramidal in shape and well supported in its fossette or box, adds considerably to the strength of the hinge but has the primary function of tending, like a compressed spring, to open the shell. Cooke (1895) states that the ligament is inelastic and insoluble in caustic potash, the cartilage very elastic and soluble in caustic potash. The cartilage, in thin pieces, is a clear red amber and of a gelatinous appearance but is readily split into horizontal right and left layers of fine fibers. At each end of the clear portion of the cartilage is a whitish, opaque pad, presumably a layer of cartilage impregnated with lime.

The hardness and brittleness of the scallop shell make difficult the preparation of sections for the study of calcareous structure. Dakin (1909), who made sections, states that prismatic and nacreous layers can not be definitely distinguished, that an irregular arrangement of crystals (chiefly aragonite) representing both these layers makes up the calcareous portion of the shell. In addition he found a trace of periostracum. Jackson (1890) states that the prismatic layer is present in the early dissoconch shell, but wanting in the adult. Drew (1906) found only the nacreous layer present in the shell of the giant scallop of commerce. Belding (1910), on the other hand, states that both nacreous and prismatic layers are present.

The present writer has examined numerous shell fractures instead of sections. A fracture along a rib of an upper valve ordinarily shows an outer white area, an intermediate dark area, and an inner white area. A fracture across the ribs shows the intermediate dark area divided by narrow, white areas at the edges of the ribs, connecting the outer and inner white areas. (See fig. 5*a*.) Occasionally a rib is found which has no evident outer white surface. The inner white surface does not extend quite to the tips of the dark ribs.

In any fracture the shell appears laminated. When color is present there are the inner white laminæ, the intermediate brown laminæ, and the outer white lamina. No further lamination within this outer white layer has been distinguished, but in some fractures cross striæ have been seen. In fractures across the ribs the laminæ appear approximately parallel to the valve surfaces. In fractures along the ribs the brown laminæ are seen to extend at an angle and toward the ventral margin from the outer white layer to the inner white layer. The laminæ of the inner white layer are parallel to the inner surface. The layer (*Hypostracum* or *clear substance*) laid down at the end of the adductor muscle is relatively transparent and is clearly and regularly cross striated in fractures. In positions abandoned by the adductor in its advance, this clear layer is overlaid by the inner white layer, and near the umbos of some shells also by the brown layer.

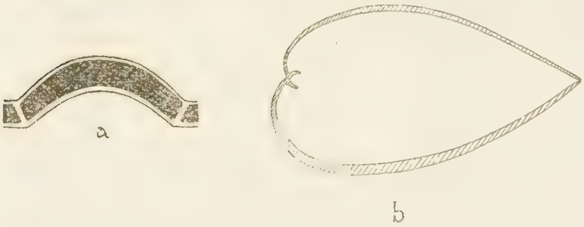

FIGURE 5.—Diagrams of shell structure: *a*, Cross section of rib and portion of adjacent grooves of left valve. (The upper white represents the outer white area which may be prismatic. The intermediate dark area (actually brown) and the inner white area are assumed to constitute the nacreous layer.) *b*, Cross section of shell through groove of upper (left) valve, rib of lower (right) valve, and "cartilage box"

Because of its distinctness from the underlying shell material, it is suggested that the generally thin outer white layer represents the prismatic. Seemingly the laminated structure, whether lying at an angle with or parallel to the inner white layer, and whether secreted within or without the pallial line, must be considered nacreous.[4] Because the brown material is found overlapping the clear layer, it is evident that the ability to deposit it is not confined to the mantle margin. From the slant of the brown laminæ, it seems, according to the accepted secretion theory, that for their deposition the outer or shell fold must be reflected sharply back over the valve margin. The brown coloring has been found by Belding (1910) to be undestroyed by acid which removes other colors from the shell.

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[4] According to Pelseneer (1906) the nacreous layer is composed chiefly of aragonite, of which, according to Dakin (1909) a scallop shell is mainly constituted. See also Horwood (1911, 1912).

A thin, but definite, periostracum is present.

MANTLE

Morphologically the mantle is considered to be a fold of the integument of the dorsal portion of the molluscan body (Cooke, 1895). In the Lamellibranchia it consists typically of two equal portions or lobes which line the two valves, which they secrete, and surround the other soft parts and the mantle or pallial cavity. Because of their structure and blood supply they are held to be very important for respiration (Dakin, 1909, considered them the principal organs of respiration) or even to be the only important respiratory organs (Pantin, 1928).

In Pecten the mantle lobes differ somewhat in size and shape even as the valves differ. The margins of the two lobes are free from the shell and, except near the hinge line, not united one to the other. Anteriorly the united portion is very short, posteriorly about equal to the width of the shell ear. Not only are the pallial lobes largely ununited, except where contiguous along the dorsum, but they are generally free from the inclosed soft parts, being adnate in *Pecten irradians* only to the adductor muscle, the pericardium, a portion of the surface of the digestive deverticula, the cephalic extremity of the branchial axis, and a portion of each of the outer labial palps. The internal epithelium of the mantle is ciliated. The external epithelium, especially that of the free margin, secretes the shell (Cooke, 1895).

Except for the margins the mantle is very thin and transparent. Across it, nerves and even blood vessels may be plainly seen. The membranous structure and the elaborately branched vascular system indicate an important respiratory function.

The free, marginal portion (figs. 3 and 4) of the mantle, peripheral to the pallial line, is thick, tough, highly pigmented, and very complex. It is supplied with an elaborate system of radial and concentric muscles, many tentacles, ocelli, and a large nerve (the circumpallial) which functions as a ganglion. Three folds of the mantle margin are recognized. The *shell fold* may be taken as extending from the pallial line, demarking the free margin from the fixed portion of the mantle, to the periphery of the shell, where the mantle is reflected inwards, and ending in the periostrachal groove. Dakin (1909), working with the European *Pecten maximus* and *P. opercularis,* states that it bears long tentacles. None was observed in *P. irradians* or reported by Drew (1906) for *P. tenuicostatus* or *P. grandis* (see p. 571).

This fold is radially convoluted to form the ribs or rays of the shell.

The middle, sensory, or ophthalmic fold extends from the periostrachal groove to the base of the flap or *velar fold.* On it (figs. 3 and 4) are the ocelli and highly extensible and contractile tentacles in a band several tentacles wide. These tentacles are smallest next to the groove and largest next to the flap. Possibly the largest or most extensible of all occur near the ears. On occasion they are extended to the surprising length of about 2 inches. The ocelli, especially the larger ones, are generally in line with the larger tentacles, but are wanting in a section ventral to the ears. They vary considerably in numbers, and in adults are more numerous on the upper lobe. Because of the variations in numbers and size of eyes, it has been suggested (Drew, 1906) that new eyes are added with growth and that the number of eyes may be an indication of age. Drew worked with scallops not only of a different species but probably much longer lived. In *P. irradians* the quota, or very near it, for the lower lobe is attained early. Specimens a centimeter long possess but few less than those of full growth. However, for the upper pallial lobe the case is different. Specimens a centimeter or slightly greater in length have about the same numbers of ocelli below and above. The ocelli of the upper lobe continue to increase until (with 40 to 55 formed in those I examined) they are about one-fourth to one-half more numerous than those of the lower lobe. The ocelli of the ear section, rather small and few in number (about a dozen, chiefly at the posterior ear), are of interest because they are exposed when the shell is closed. Dakin (1909) noted that in various species the ratio of the number of eyes on the upper lobe to the number on the lower lobe increased with the relative flatness of the upper valve, but that even if the upper valve was the more convex the upper lobe had more eyes than the lower.

The abundance of scallop eyes and the unequal distribution between the two mantle lobes have led to considerable discussion. Patten (1886) has queried the scallop's need for many organs of vision if two suffice for other forms. Dakin believed numerous eyes were needed because they were not movable in various directions and images would be formed only of objects directly in front of an eye. A reasonable explanation for the greater abundance of eyes on the upper lobe seems more difficult to find. It is perhaps worthy of notice that this uneven distribution tends to equalize the light perception of the two valves.

The ocelli of Pecten have been the object of much study since Poli (1795) sketched their external appearance, recognized their resemblance to the vertebrate eye, and named some of the parts. Garner (1837) stated that scallops possess "small, brilliant, emeraldlike ocelli, which, from their structure, having each a minute nerve, a pupil, a pigmentum, a striated body, and a lens, and from their situation at the edge of the mantle, where alone such organs could be useful, and also placed, as in Gasteropoda, with the tentacles, must be organs of vision." Krohn in 1840, according to Sharp (1884) and Dakin (1910), greatly advanced knowledge of the structure of the ocellus which he designated a closed vesicle. Apparently he was the first to note the septum and the division of the nerve into two branches.

The "modern" period in the study is taken to begin with the paper by Hensen (1865), who not only advanced knowledge of eye structure but also proved something of a seer when, after remarking upon the clearness with which details of the eye may be observed, he asked "but how much toil (Mühe) will be necessary before the entire structure of this cubic millimeter will be understood?" In the many years that have elapsed a great amount of minute attention has been given the structure of this diminutive organ and presumably the end is not yet.

Among later accounts may be mentioned Hickson (1880), Patten (1886), Rawitz (1888), Schreiner (1896), Hesse (1900, 1902, 1916), Hyde (1903), Dakin (1909, 1910a), and Küpfer (1916). Of these only Hyde worked with *P. irradians* or other American scallop. Some of her findings were so different from those of other investigators that Dakin (1910a), working with European species, made special but unsuccessful efforts to confirm them. The retina evidently is very complicated and the chief cause of disagreement. The paper by Dakin (1910a) presents a clear, detailed, and very useful account based on extensive personal investigations and with a careful survey of the literature. The book by Küpfer (loc. cit.) is unusually elaborate and complete. Notable features are additions to the knowledge of the outer layer of the retina and of the development of the eyes, and a detailed comparative anatomical discussion. The recent account (Light, 1930) of light receptors in Mya is of interest.

I have examined several eyes fixed in formalin, stored in alcohol, and cleared in glycerin. Although histological details were not determinable, major structures could be distinguished. Figure 6, showing only the general structure, is based on dissection of such material.

The following brief account is based largely on that of Dakin:

The eyes are situated at the end of short stalks located among the tentacles of the middle fold. The stalk is composed chiefly of connective tissue and contains muscle fibers, large blood spaces, and the optic nerve. This nerve has been supposed to come from the ganglionic circumpallial nerve, but according to Dakin (1910a) most of its fibers connect directly with the visceral ganglion. The epithelium is pigmented around the eye forming what has been termed an iris (Patten, 1886). In front of the lens it is clear and is termed cornea.

Separated from the cornea by a layer of clear connective tissue is the lens, which is composed of many transparent cells of unusual shape and arrangement. The inner face of the lens is much more convex than the outer. Back of the lens and overlying the retina is the membranous septum.

The complex, inverted retina has been considered to consist of various numbers of layers but, according to Dakin (1910a), is best considered as of two, an outer layer of distal sense cells and an inner one of rod cells and rods. The outer layer is innervated by the outer or distal branch of the optic nerve which enters from the front through the septum, the inner layer by the inner or proximal branch which enters through the periphery.

Back of the retina are two prominent layers, each of which has been termed "tapetum." Patten (1886) referred to the inner or frontal of these, which is refractive and gives the eye its metallic glitter, as the argentea—an appropriate name. However, this layer previously had been termed "tapetum" by Krohn who discovered it (Dakin, 1910a). The outer or abfrontal of these two layers was designated "tapetum" by Patten but probably is best referred to as pigment layer (Dakin, loc. cit.). The layer of connective tissue surrounding the abfrontal half of the optic vesicle—that is, that portion back of the septum—was termed "sclerotica" by Patten, to which some authors have objected.

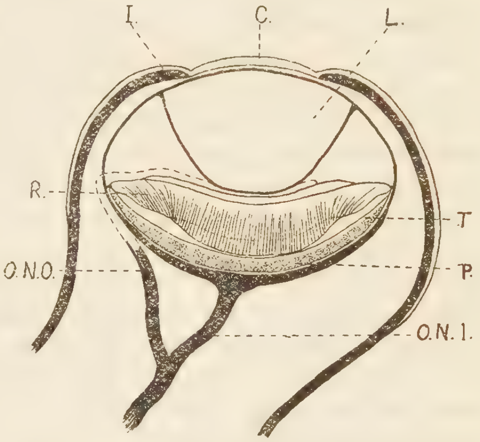

FIGURE 6.—Sketch of eye on dissection of unstained material cleared in glycerin. *C*, Cornea; *I*, iris, made up of pigmented and clear layers; *L*, lens; *O. N. I.*, inner branch of optic nerve which spreads around the base of the optic vesicle to the edge of the retina; *O. N. O.*, outer branch of optic nerve, the latter course of which, leading to the face of the retina, was not followed in these dissections; *R*, retina overlain by septum (not designated) with three noticeable layers (an outer or outer ganglionic layer, a layer of rod cells, and an inner layer of rods); *P*, pigmented layer (tapetum of Patten); *T*, tapetum (argentea of Patten)

Although there has been so much work on the ocelli, most of it has been histological so that knowledge of their functioning still is rather unsatisfactory. From their structure they appear to be organs of vision. However, their very elaborateness and high development only add to the puzzle, for if such highly organized structures are organs of sight, their vision would be expected to be excellent and not only easily demonstrable but evident beyond a doubt. On the contrary, although scallops undoubtedly are sensitive to light, any image vision they possess is so poor or so limited as to be difficult to establish. One difficulty is in obtaining specimens that react normally (Wenrich, 1916, states that only scallops from very shallow water are satisfactory). Another is that scallops frequently cease to react after repeated stimulation.

Marine mollusks have been grouped according to their reaction to changes in light intensity into those which react to increases and decreases, those which react to increases only, and those which react to decreases only. It seems generally agreed that scallops belong with those that react to decreases only. With normally acting individuals a shadow cast on the eyes causes quick complete or partial closing. Using small objects to produce local shadows, Rawitz (1888) found that the shadow must fall on several eyes to produce a reaction. Wenrich (1916), using instead local illumination through slits or small holes in a disk, found that cutting off the light from as few as two eyes (the smallest number tested) produced definite, although sometimes local, reaction.

It has been held that, in addition to being sensitive to decrease in illumination (shadows), scallops were sensitive to movement of objects. To test this Wenrich (1916) placed individuals which had been found to react to decreases in illumination, but not to increases, in a glass dish in one end of a box at the opposite end of which was black paper. Against this black background small white cards of various sizes were moved upward to a level with the scallops. It was believed, by this means and proper precautions to prevent uncontrolled light changes, that the only change in illumination of the scallop eyes was increase (to which, as above noted, the scallops had been found not to react) and, therefore, that reactions were attributable not to changes in illumination but to perception of the movement of the object. Unfailingly the animals gave immediate and vigorous responses by closing the valves or by contraction movements of the velar folds and tentacles. The reactions occurred with both slow and rapid movements and also when downward or horizontal. The smallest effective white card was 1.5 centimeters square at a distance of 35 centimeters (the distance used throughout these experiments).

Uexküll (1912) placed a scallop in one aquarium and a starfish—its principal enemy—in an adjacent aquarium. There was no response until the starfish moved, when the scallop instead of closing extended its tentacles in the direction of the starfish.

According to my observations, movements, particularly sudden movements, of an object within a few feet of freshly caught scallops and in their line of vision (even when, as in Wenrich's experiments, an increase in illumination is involved), caused complete or partial closing. When a scallop reopens, long tentacles of the adjacent sector may or may not follow the object as it moves.

Probably there is sufficient evidence that the ocelli are organs of vision, but a better knowledge of their functioning and usefulness to the scallop is much to be desired.

The very extensible tentacles of the middle or ophthalmic fold have been supposed (Uexküll, 1912) to be endowed with both chemical and tactile sensitivity. Dakin (1910) found that the introduction of a chemically irritating substance, as one obtained from starfish, caused scallops to swim and concluded that the perception was by the "sensory tentacles." The writer does not find that this chemical sensitivity has been traced definitely to these tentacles. Tactile sensitivity is readily demonstrated.

Sections of the margin of the mantle, cut from a living scallop by the author and placed in a dish of salt water, soon relaxed with some extension of the tentacles of the middle fold. Touching one of these tentacles caused contraction not only of the tentacles but of the whole excised portion—an action not caused, in my observation, by touching the tentacles of the velar fold. However, after a portion of the mantle was so cut as to separate the middle velar folds from the tissue containing the circumpallial nerve, there appeared to be no contraction of the piece as a whole or of the parts. Touching a tentacle did not even cause contraction of that tentacle.

The third fold of the mantle margin, sometimes referred to as velum, but here termed "velar fold" or "flap," is the most prominent and distinct of the three. (Figs 3 and 4.) It is wide and well supplied with muscles, is brightly marked (as with yellow, black, and white), and, near its free margin, bears alternately large and small tentacles (the guard tentacles) in a somewhat zigzag row. The velar folds play an important part in swimming and presumably in feeding. The free margins may be brought together so that a continuous wall or curtain is formed. When the scallop lies at ease with the valves well separated, they are extended toward each other, nearly at right angles to the plane of the valves, meeting or nearly meeting close to the posterior ribs.

The so-called guard tentacles, which are not considerably extensible, are directed in a convex arc toward those of the other flap to form a screen through which the food and water is drawn. If an indrawn object, such as a large carmine grain, hits a tentacle, the tentacle makes a peculiar flicking motion, but the shell is not closed nor the object otherwise prevented from entering. Moreover, a touch with a prod, at least at times, does not cause the valves to close. While the valves remain apart, whether the opening is wide with the velar folds extending up and down, or narrow with these folds horizontal, a more or less complete screen of these "guard" tentacles is maintained. With important tactile function apparently wanting, a chemical, olfactory, or taste function is strongly suggested.

To test this a starfish was crushed in a mortar and a cloudy liquid irritating to scallops obtained. A freshly caught scallop was placed in a rectangular glass dish. When the scallop had opened wide its shell and arranged the mantle margin with the guard tentacles across the inhalent opening and well separated from the tentacles of the middle fold, the irritating cloudy liquid was gently introduced directly to the guard tentacles by a special pipette with bent tip. Repeatedly and unfailingly as the cloudy liquid came to the guard tentacles, these were sharply withdrawn and the shell violently closed. Beyond question the tentacles of the middle fold did not enter into the response and it seemed clear that the exciting substance had not entered the pallial cavity when the reaction began. Pipetting the same liquid against individual extended tentacles of the middle fold caused no reaction beyond some contraction of the tentacles touched, as when water was used—evidently a tactile response. Squirting sea water against the guard tentacles failed to induce shell closing. These experiments seem to show that the guard tentacles possess an olfactory, gustatory, or some chemical sensitivity.

Anterio-dorsally and posterio-dorsally, near the ears, the velar folds are narrowed with some abruptness and are without tentacles. When the valves are apart these folds are so extended that they touch, or nearly touch, at the ventral limit of the posterio-dorsal narrowing, bounding a well marked exhalant opening. For the young this arrangement of the folds has been termed a pseudo-syphon. The opening formed by the anterio-dorsal narrowing may be confluent with the large inhalant opening (extending from the ventral limit of the exhalant) or separated. The ciliary current through it is inhalant (and the only inhalant current when the shell is closed), but powerful exhalant currents occur during swimming and for the ejection of material rejected by the palps.

An account of the action of the mantle during swimming will be found in the description of that process.

GILLS

In the Lamellibranchiata, gills are of unusual importance. Not only do they produce the water currents which bring food and oxygen and carry away carbon dioxide and other wastes, but they also separate food organisms from the inhalent current and convey them toward the mouth. It is even claimed that they absorb food directly from the water. Presumably, in spite of recent claims to the contrary, they are important organs of respiration. In addition to being of manifold functional importance, the gills provide morphological evidence of special value for classification, as previously noted.

STRUCTURE OF THE GILLS

The minute structure of the gills, especially the filaments, has been described or figured by Kellogg (1892), Drew (1906) and Dakin (1909). The present account will not enter elaborately into the histology and will depend upon illustrations for structural details and arrangements. Studies have been largely with living or fresh material.

In the section dealing with classification it was noted that the filaments of the gills are reflected and are held one to another by spurs (not vascular connections). As now interpreted there are two gills (or ctenidia of branchiæ)—one on the right and one on the left side of the body. Each gill (see fig. 7*a*) consists of two demibranchs and a branchial or ctenidial axis from which they are outgrowths. In turn each demibranch consists of two lamellæ (direct and reflected)—one composed of the direct limbs of the filaments, the other of the reflected limbs. The demibranchs are supported only by the axis, the inner lamella of each gill being free from the visceral mass, the outer from the mantle. The lamellæ are not flat but accordion pleated or folded (plicate gills). This folding, which is steep next to the axis and relatively shallow and broad at the outer edge, is due to the arrangement of the branchial filaments, which are grouped in closely compressed folds at the axis and are united at thin plates at their tips.

Two distinct types of filaments occur (heterorhabdic gills). At the bottom of each groove is a principal filament. Making up the convex folds between are 16 ordinary filaments. (See fig. 7*b*.) As shown in Figure 3 the gills are roughly crescent shaped, being greatly curved and with the filaments shortened toward the ends of the axes. From the branchial axes and from the free edges of the reflected lamellæ, the principal filaments spread fanwise and draw the ordinary filaments (which typically are held an approximately uniform distance apart by the spurs) nearer and nearer to their level and thus broaden and flatten the lamellar folds.

The ordinary filaments are slender and relatively simple. (See figs. 7 and 8.) Around a thin-walled, flattened, chitinous tube is an epithelium which is thickest at and near the frontal face, whence arise, along its full length, the very numerous frontal cilia. Near the front on either side are the long and powerful lateral cilia. (See fig. 7*c*.) The elongate latero-frontal cilia described for Mytilus, Ostrea, and various lamellibranchs have not been found in the scallop, nor have I succeeded in demonstrating that the most lateral of the frontal cilia (in a latero-frontal position) function as would typical latero-frontal cilia. Dividing the filamentary tube into frontal and abfrontal portions is the intrafilamentary septum. The connective spurs are situated at frequent, regular intervals at the abfrontal edge. These spurs evidently are highly muscular and the filaments somewhat so, as will be discussed more fully later. The

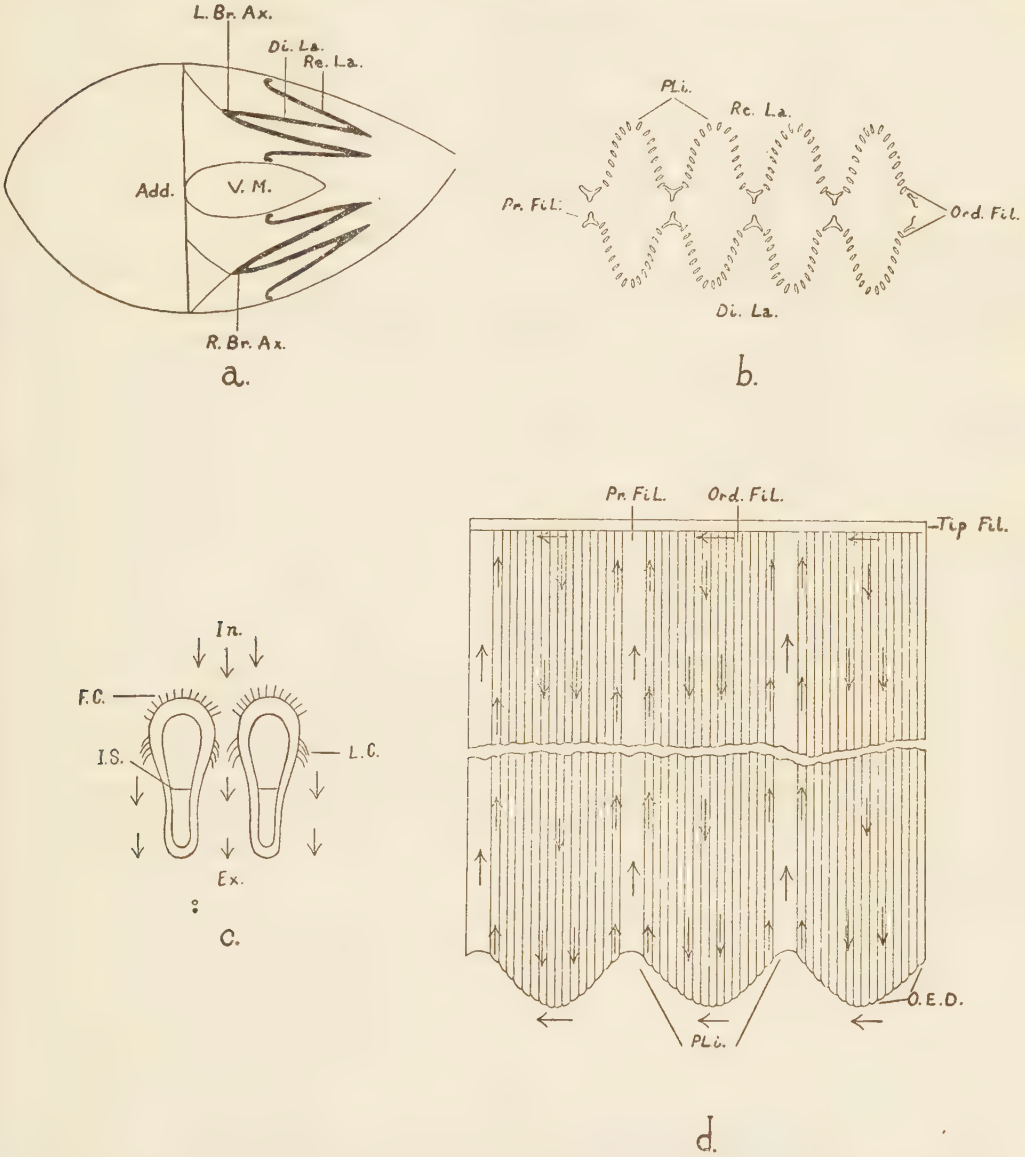

FIGURE 7.—*a*, Diagrammatic transsection of gills showing their suspension and position relative to adductor, visceral mass, and pallial lobes; *b*, longisection through portion of outer demibranch of left gill (transsection of plications and filaments of direct lamella (below) and reflected lamella (above)); *c*, transsection of adjacent ordinary filaments, showing cilia and currents produced by lateral cilia; *d*, superior view of portion of reflected lamella of outer demibranch of left gill (very diagrammatic); *Add.*, adductor muscle; *Di. La.*, direct lamella; *Ex.*, exhalant current; *F. C.*, frontal cilia; *In.*, inhalant current; *I. S.*, intrafilamentary septum; *L. Br. Ax.*, left branchial axis; *L. C.*, lateral cilia; *O. E. D.*, outer edge of demibranch; *Ord. Fil.*, ordinary filament (in "*b*" direct (below) and reflected limbs of the same filament); *Pli.*, plications; *Pr. Fil.*, principal filament (in "*b*" direct (below) and reflected limbs of the same filament); *R. Br. Ax.*, right branchial axis; *Tip. Fil.*, united tips of filaments (very diagrammatic)

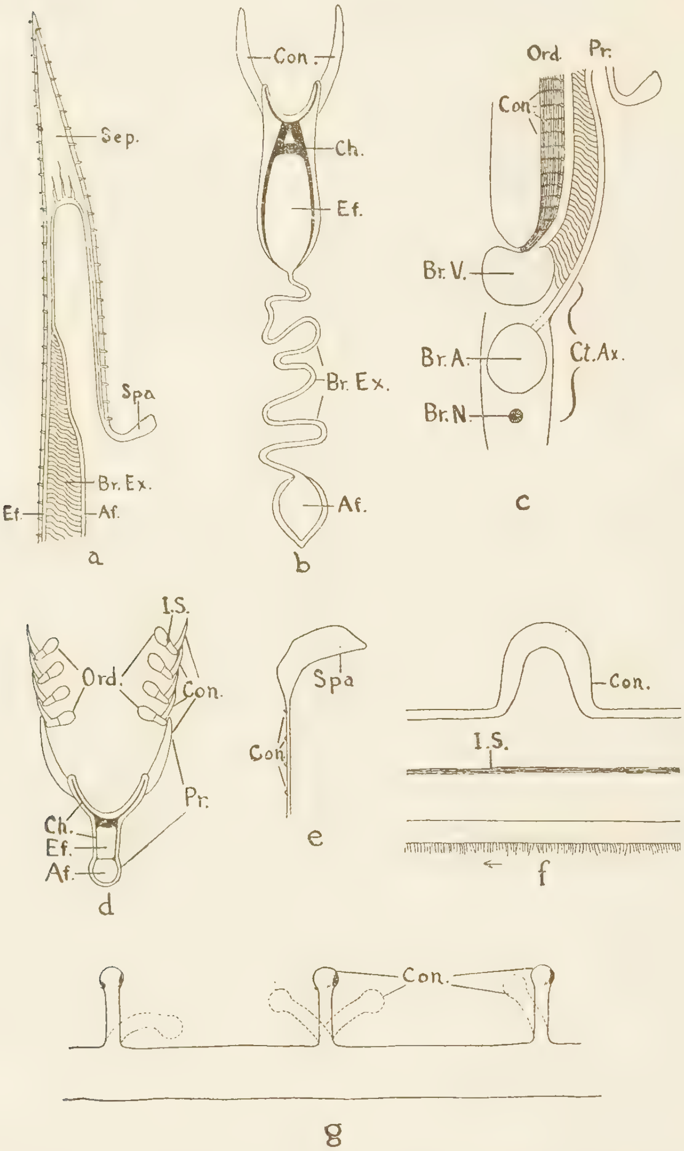

FIGURE 8.—Diagrammatic sketches of gill filaments; *a*, A principal filament; *b*, cross section of a principal filament, through branchial expansion; *c*, ctenidial or branchial axis with principal and ordinary filaments, etc.; *d*, cross section, between branchial expansion and interlamellar septum, of a principal filament and adjacent ordinary filaments; *e*, distal portion of an ordinary filament, spatulate tip drawn carefully from specimen; *f*, an ordinary filament with a contracted spur and with frontal cilia; *g*, an ordinary filament with connective spurs expanded and in various positions to show power of movement. *Af.*, afferent branchial vessel; *Br. A.*, branchial artery; *Br. Ex.*, branchial expansion; *Br. N.*, branchial nerve; *Br. V.*, branchial vein; *Ch.*, chitinous supporting structure; *Con.*, connective spurs; *Ct. Ax.*, ctenidial axis; *Ef.*, efferent branchial vessel; *I. S.*, interlamellar septum; *Ord.*, ordinary filament; *Pr.*, principal filament; *Spa.*, spatulate tip of filament

spurs bear active cilia. The ordinary filaments originate nearer the center of the face of the branchial axis than do the principal filaments, and connect only with the efferent branchial vessel.

The principal filaments are much greater in diameter than the ordinary filaments and stiffened more with chitin. (See fig. 8.) In addition they are much more complex. The connective spurs are much enlarged and frontal, rather than abfrontal, in position. The basal or *branchial expansion* and *interlamellar septum* occur on every principal filament, but on these only. The principal filaments, so numerous they lie almost one against another along the branchial axes, provide nearly all the transverse support for the gills. The interlamellar septa are important in maintaining the reflected lamellæ in position. Vascular connection is not only with the efferent but also, along the interlamellar edge and the branchial expansion, with the efferent branchial vessel. The presence of abfrontal cilia is indicated in my experiments by the movement of fine carborundum along the abfrontal edge of the branchial expansions toward the branchial axis.

Filamentary nerves of ordinary and of principal filaments are described by Dakin (1909), who figures a small nerve at the interlamellar edge of an ordinary filament. Kellogg (1892) figured no filamentary nerves, Drew only those of the principal filaments. The behavior of the filaments indicates nervous structures in both types.

The branchial axis is decidedly tough and firm and consists largely of connective tissue, but with a good supply of muscle fibers (Dakin, 1909). It contains the branchial nerve and afferent and efferent vessels. The epithelium is ciliated. The suspension or attachment of the axis evidently is adapted to the animal's existence with the right side down. (See fig. 7*a*.) Anteriorly each axis is attached for a very short distance to the lateral edge of the body mass (surrounding the stomach) and to the adjoining mantle. For the left axis this is over the pericardium. The next attachment is to the sheath of the adductor muscle rather close to the pallial lobe. This attachment of the left lobe continues to the posterior limit of attachment, somewhat overlapping the rectum. For the right axis conditions are more complicated. The simple direct attachment to the adductor sheath continues only a short distance, about half the length of the kidney. Ventrally and posteriorly to this, the support may be said to be twofold. On the one hand the axis is attached to the mantle lobe, on the other to the sheath of the adductor. (Fig. 7*a*.) Attachment to the adductor is by two connective tissue flaps which serve to raise the gill above the pallial lobe. The anterior and larger of these flaps is roughly triangular. Considered as an isosceles triangle, the base lies along the branchial axis, one side (attached) along the dextro-posterior margin of the kidney (or the course of the branchial nerve outside of the gill), the apex near the right urinogenital opening and the other side (free) along the course of the fourth lateral pallial nerve. At the posterior limit of attachment the second flap extends from the mantle along the adductor sheath securing the axis thereto at a considerable distance from the lobe. Each axis continues around the adductor considerably beyond the posterior limit of attachment.

FUNCTIONS AND ACTIVITY OF THE GILLS

Respiration.—The functions of the gills have been briefly alluded to in the paragraph introductory to the discussion of the gills. It was there noted that recent denial of important respiratory function has been made. Hitherto it has been almost universally held that the gills of lamellibranchs were important for respiration.

Although considerable respiratory function has been attributed to the pallial lobes, the gills are generally assumed to be the principal respiratory organs. The basis of this assumption is to be found in their typical, finely tubular structure and the fact that they are bathed as are no other suitable structure by the inhalant water current. In 1928 Pantin wrote that "A Lamellibranch mollusk feeds with 'gills,' so called, which have no respiratory function." Later, in a letter, he qualified this slightly, but admitted only a limited amount of respiratory function, as of any exposed surface. Referring to Dakin (1909) he stated that the mantle appears to be the chief organ of respiration owing to its extremely effective blood supply and probable slow metabolism, whereas the metabolism of the gill filaments is extraordinarily high, so that it is quite probable that all the oxygen absorbed by the gills is required for their own activity. He further refers to Dakin's (1909) conclusion that the heart receives completely oxygenated blood from the mantle and "*probably* [the italics are mine] only incompletely oxidized" blood from the gills. Doubtless this makes a good case for questioning, but hardly for definitely denying that gills are organs of respiration.

Considering the arguments advanced, it seems reasonable to continue to consider that the principal filaments with provisions for efficient vascular circulation and with structures so well suited for respiration as the branchial expansions, perhaps aided to an important extent by the interlamellar septa, are important respiratory structures. The extent of the branchial expansions alone are sufficient to constitute a very considerable gill. Indirectly the gills surely are important for respiration, for they produce the all-important oxygen bringing and CO_2 removing water current.

CILIARY ACTION OF THE GILLS

If there is some question as to whether or not the gills are important organs of respiration, there is none that they are important organs of feeling. The action of the lateral cilia, as shown by Wallengren in 1905 (see Yonge, 1926) and Orton (1912), create the inhalant-exhalant water current. From this current the gills filter out food organisms, often with much material that is undesirable, and pass them toward the mouth. For the filtering action the gill filaments of some mollusks are provided with long, latero-frontal cilia which interdigitate with those of adjacent filaments and beat slowly with the effective stroke toward the center of the front of the filament. As previously noted no such cilia have been found for Pecten. However, incoming organisms or other particles are entangled by the mucus secreted by the filaments and thus effectively removed from the current.

Particles caught in the mucus or otherwise brought to the frontal surface of the filaments come under the influence of the frontal cilia. Depending on whether they impinge on the filaments in the grooves (that is, on the principal filaments and those on either side) or on the tops of the folds (that is, on the filaments intermediate between the principal filaments) (see figs. 7*b* and 7*d*), they are carried by the longitudinal beat of the frontal cilia to the inner or outer edge of the lamella. At these places the frontal cilia beat transversely to the filaments in such a way as to convey the particles toward the palps. (Fig. 7*d*.) As pointed out by Kellogg (1910, see also Kellogg, 1915), this unusual condition provides a food-selective mechanism in the gills. If suspended particles are abundant, as when the water is heavily laden with silt, the material on the gills becomes imbedded in strings of mucus secreted in increased amounts, stretched across the filaments. The currents in the grooves tend to carry these strings toward the branchial axis; but the currents on the tops of the folds prove more effective and carry the material, including that in the grooves, to the outer edge of the demibranchs. It is probable that ordinarily the masses so carried, being heavy and no "food groove" being present in our scallop (although a shallow one is figured for *P. maximus* by Orton, 1912), drop off the gill. Under some circumstances, however, as I have observed experimentally, the material carried there in long strings to the outer edge is not so heavy as to drop and is carried toward the palps. When not too abundant, apparently most material falls into the grooves and, unless it is sharp or irritating so that it greatly stimulates mucus secretion or causes the gills to "writhe," is carried either to the base or tips of the filaments, where a strong ciliary current conveys it to the palps.

A few observations on the rate of travel of particles along the frontal cilia paths were made in these investigations. Most of the observations were of the speed of particles or of small mucus strings conveyed transversely to the filaments, close to their tips and toward the palps. (Fig. 7*d*, at top.) Rate of travel often could be seen to be very irregular. Sometimes a particle would hit a hump in the gill and stop or almost stop. At other times there would be obvious but less drastic slowing. However, there were many times when progression was more regular. Most of the speeds recorded fell close to 1 millimeter per second at about 21.5° C. (21.2° C.–21.8° C.). A few times notably higher speeds were noted (up to 2.3 millimeters per second) with small particles which went the distance without interference and evidently were in the most favorable current. Determination of rate of travel along the filaments was much more difficult because of conflicting currents and the "writhing" of the gills. Therefore, only a few readings were obtained. Speeds recorded were close to 0.4 millimeter per second.

It may be remarked that the ciliary motion of lamellibranchs is not reversible, nor is there evidence of nervous control of the activity of cilia (Gray, 1928). This activity is, however, affected by temperature, hydrogen-ions, and other water conditions. (See the various papers by Gray, also Galtsoff, 1928 and 1928a.)

BRANCHIAL MOVEMENT

Although muscle fibers have been found in the branchial axis, the movements of the gill and of its parts indicate much more muscular tissue than would be supposed from morphological studies. Kellogg (1910) noted the writhing and swaying of the gills when much material was deposited upon them. Touching a filament with a needle causes contortions for a considerable distance along a lamella. Examined in more detail, motion is found to consist to a large extent of elongation, contraction, and pivotal movement of the connective spurs (see fig. 8, *f* and *g*), and of the extreme transverse movement of the principal filaments. Obviously one effect of the elongation and contraction of the spurs is to vary the interlamellar space, and this may be important for filtering (as by permitting large particles to pass through or by removing more effectively abundant fine silt). The transverse movement of the principal filament is remarkable. As shown in Figure 8, *b* and *d*, the frontal surface is highly concave with widely extending lateral edges which bear the large connective spurs. In this movement these edges may be brought close together or turned abfrontally until they and the spurs lie against the sides of the axis of the filament. Excised portions of principal and ordinary filaments have been seen to bend longitudinally to a marked degree and to respond to stimuli. Presumably the principal if not the sole purpose of branchial movement is to rid the gills of irritating substances or objects.

GREENGILL

In the winter of 1927–28, the writer collected scallops in western Bogue Sound, N. C., which were found to have bluish green gills. Examination of fresh material revealed greenish pigment in the epithelial layer of the ordinary filaments. A sketch from this fresh material shows an irregular band of pigment (green granules) on the sides of the filament near the front. From the arrangement of the granules it does not seem that they were grouped in "secretion cells" as Lankaster (1886), Herdman and Boyce (1899), and others in Europe, and Mitchell and Barney (1917) in this country have reported for greengill oysters. Nevertheless there is reason to believe that the greening is of the same nature in oysters and scallops. It appears that with oysters the green granules are not always confined to the "secretion cells" (Ranson, 1927). As is generally reported for oysters with greengills, these greengilled scallops were in very good condition. The very region in which they were found had been abandoned by oystermen because the oysters became greengilled. There is much similarity in the feeding and location of scallops and oysters (both being forms which live on, rather than in, the bottom).

Although it was not learned whether *Navicula osteraria* was present, because it has been reported with such remarkable uniformity in connection with the greening of oyster gills, it may be taken as indicated that it occurs in this region of greengilled oysters. Certainly there is no reason to believe that food organisms or material which would color the gills of scallops would not affect those of oysters and vice versa. Although I have seen no other references to the greening of scallop gills, that is not surprising in this country, at least, for here the gills are removed from the market product and no economic interest attaches to their color.

LIPS

The labial palps (fig. 3) may be considered specialized, lobate prolongations of the lips. There is a pair of them on the right and left sides of the mouth, between the mouth and the end of the gills. The outer palp of each of these pairs is a continuation of the dorsal lip, the inner of the ventral. Between them is the oral groove. The adjacent surfaces of the palps of each pair are ridged and very elaborately ciliated. It is the function of the palps either to transmit to the mouth or to reject as unsuitable the material delivered by the gills. In the selection the muscular movements of the palps aid the elaborate sorting action of the complex ciliary arrangement. The ciliation of the palps of scallops has been studied and figured by Kellogg (1915). For detailed accounts of palps see Churchill and Lewis (1924) and Mathews (1928).

The lip ridges leading from the palps to the mouth (or the opening into the œsophagus) are, in the scallop, most remarkably produced into much branched, "tufted" prolongations (indicated in fig. 9*c*). In life they are active and evidently ciliated. As noted by Dakin the branched structures from the two lips interlock (or overlap) over the mouth so that there are, in effect, two oral openings, one for each groove.

ALIMENTARY TRACT

The mouth or opening into the oesophagus is wide and dorso-ventrally flattened. From this the oesophagus rapidly tapers and thereafter, bending to the left, continues in its narrowed form to join the stomach. The action of the cilia of its epithelial lining conveys food and other material to the stomach.

The stomach is of a very complex shape which is better illustrated than described. In Figure 9, *a* and *b* are from plaster casts, and *c* and *d* from dissections. The numerous, small branches are the beginnings of the diverticula. A considerable portion of the stomach walls are ridged or folded in a complex manner. Many ridges (fig. 9*d*) on the right or lower side converge toward the opening to the mid-gut. This system of ridges leads, in part, from the ducts of the diverticula.

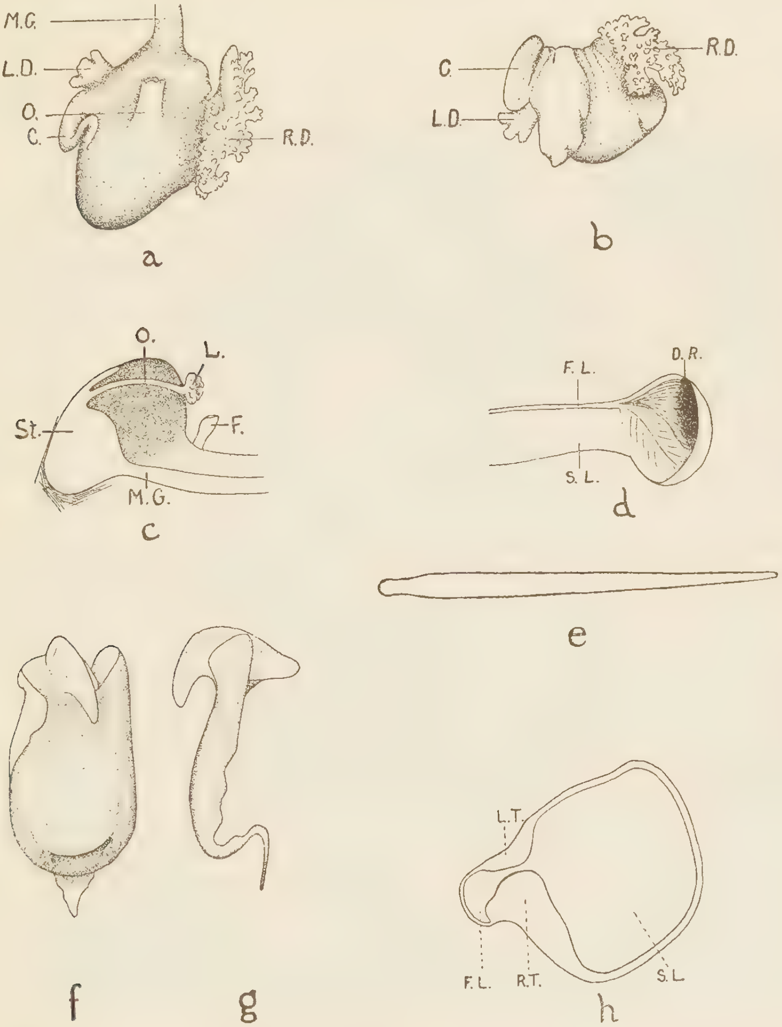

FIGURE 9.—*a*, Dorsal aspect of stomach; *b*, posterior aspect of stomach (*a* and *b* from plaster casts); *c*, dextral view of section through esophagus, stomach, and portion of mid-gut; *d*, interior view of right (lower) side of stomach; *e*, crystalline style; *f*, posterior, and *g*, lateral views of gastric shield; *h*, cross-sectional sketch of mid-gut close to stomach, antero-ventral view (looking toward stomach); *C.*, caecum; *D. R.*, duct of right diverticula; *F.*, foot; *F. L.*, food lumen; *L.*, lips; *L. D.*, duct of left diverticula; *M. G.*, mid-gut, with style lumen; *O.*, œsophagus; *R. D.*, basal portion of right diverticula

The epithelium of the stomach is possessed of very active cilia which produce a complex circulation of the stomach contents. In an opened stomach, introduced fine particles of chalk (superior to carmin in visibility in such a situation) can be seen going in and coming out of the ducts to the diverticula. Material on the ridged surface of the ducts always comes out and, at least from diverticula of the right side, follows the converging furrows to the mid-gut.

In the stomach lies the gastric shield which doubtless takes the thrust of the rotating style, as described for other lammellibranchs. The shield (fig. 9, *f* and *g*) is horny in consistency, ornately shaped, and of a somewhat greenish yellow color, with opalescence, which resembles rather strikingly the color of the lining of the mid-gut. Nelson (1918) believes the substance of the shield probably to be in the nature of chondrin, Gutheil (as noted by Yonge, 1926a) that it is secreted by the underlying epithelial cells and Yonge (1926a) that it is formed of fused cilia.

Extending into the stomach is the rodlike gelatinous crystalline style, clear greenish amber in color and sometimes spirally marked. The shape, with the stomach contents removed from the "head," is shown in the accompanying illustration. (Fig. 9e). Various workers (Barrois, 1889–90; Mitra, 1901; and Mackintosh, 1925), working with various genera have found the style to consist principally of water (about seven-eighths) and globulin (about one-eighth), and to contain digestive enzymes (Coupin, 1900; Mitra, 1901; and Dakin, 1909; Nelson, 1918; and Yonge, 1926a). The style dissolves in water but is preserved by formalin, is quite firm in a freshly opened animal, and is concentrically laminated. The head, in the stomach, is found buried in a mass of food material which must be washed or teased away before the shape of this end can be determined.

The markings to be found in or on some styles evidently are inclusions of food or some associated substance and presumably are spiral because of rotation of the style. Rotation of the style of lamellibranchs apparently was first observed by Nelson (1918) who opened the stomach for the purpose. More recently it has been observed through the shells of young mussels (Churchill and Lewis, 1924) and oysters (Yonge, 1926a), although I have not succeeded in observing it in Pecten. All observations with which I am familiar are to the effect that, viewed from the head end, the style rotates clockwise. Nelson (1918 and 1925), Allen (1921), and Orton (1924) have supposed one of the functions of the style to be the return of food from gut to stomach. If the style markings are inclusions of material being so returned, the indicated direction of rotation is clockwise, if "streamers" from the stomach, it is counterclockwise. From a consideration of the findings and opinions of recent workers it seems probable that they are the former and, therefore, that the rotation is clockwise. Moreover, in larvæ identified as *P. irradians* I have observed the stomach contents to rotate rapidly in a direction corresponding with this clockwise rotation of the style. It is supposed that the style is not only continually revolved but also pushed into the stomach (against the gastric shield) where the head is continually dissolved. Frequently, in the stomachs of scallops possessed of a firm style, mingled with the rest of the stomach contents there is to be found a sticky, yellowish substance which apparently and presumably is dissolved material of the style.

The nature and functions of the style have fascinated zoologists who have evolved many theories. Of these the following may be worthy of mention: To act mechanically upon the food, apparently as a sort of chewing organ; to prevent the food passing too quickly through the alimentary canal before digestion can take place; reserve food material; an excretion; to lubricate the undigested food material; a digestive ferment. That the style contains an enzyme which converts starch to sugar seems established, but just how important the enzyme of the style is in the economy of digestion, has yet to be determined. Nelson (1918, 1925) believes that one

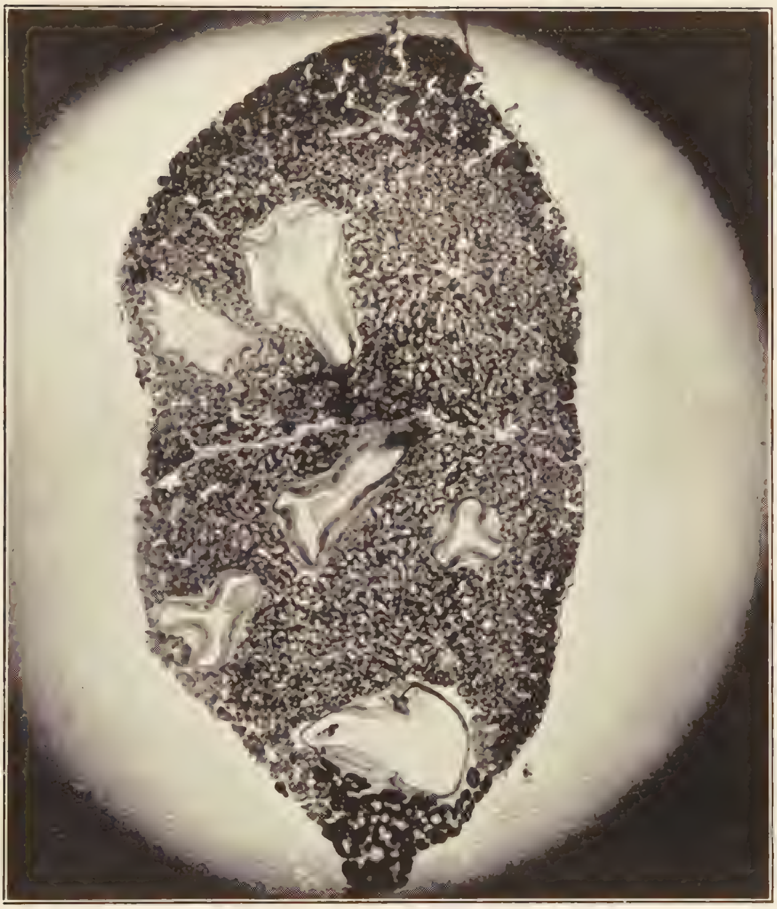

FIGURE 10.—Cross section through viscereal mass, looking away from the stomach (left and right reversed), and showing the intestine cut in six places. Close to the bottom lies the descending portion of the intestine (mid-gut), leading from the stomach; above and to the left that portion leading toward the anus. Below the lowest section lies testicular tissue; above and occupying most of this portion of the mass, ovarian tissue. Sperm and eggs abundant. Iron hæmatoxylin

of the principal functions is to rotate the food material received from the œsophagus and so aid mechanically in the sorting of food and that an important amount of food material may be caught up by the style and returned to the stomach. In addition, this stirring of the food by the style with the continual dissolving of the head of the style would seem ideal for mixing the enzyme of the style with the food material.

I have not noted a scallop freshly killed soon after removal from the water which did not possess a style. A special search of scallops in poor condition has not been made.

Nearly surrounding the stomach is a mass of tissue which in *P. irradians* is of a dark green color. Earlier writers termed this liver or hepato-pancreas. Dakin, (1909) who studied the contents of this tissue (Pecten) and found that an extract would digest proteids, starch, and fats (that is, contained amylase, protease, and lipase), naturally assumed that these substances were discharged into the stomach to prepare the food for absorption by the intestine, and gave the name digestive gland. Yonge (1926a) working with *O. edulis*, concludes that these substances are not so discharged but that the function of the organ is intracellular digestion, and employs the term "digestive diverticula," which is here adopted. "Circumstomachal organ" or "circumstomachal tissue" would be reasonably definite as to designation and noncommittal as to function.

The intestine of scallops, as figured by Drew, Dakin, and Belding, is a short affair scarcely more convoluted than that of an oyster. In local specimens, dissection and sectioning reveal a long intestine with several convolutions within the visceral mass (figs. 10 and 11), as does examination of free-hand sections of a specimen from Massachusetts. The style sack or cæcum connects by means of a narrow slit with the food passage, which it greatly exceeds in cross section. (Fig. 9*h*.) Typhlosoles are large and distinct. Ciliation, general throughout the intestine, is especially heavy in the style sack. The intestine, leaving the visceral mass, passes along the right digestive diverticula and, as the rectum, through the pericardium and ventricle, thence around the adductor muscle nearly to the tip of the visceral mass where it ends in a trumpet-shaped anus.

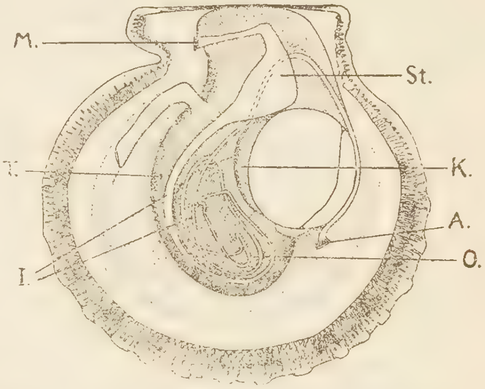

FIGURE 11.—Sketch showing alimentary canal with much convoluted intestine *in situ* with other parts. *A*, Anus; *I*, intestine; *K*, kidney; *M*, mouth; *O*, ovary; *St.*, stomach; and *T*, testis

FOOT

The small, roughly cylindrical foot of the adult scallop (figs. 3 and 11) is useless for locomotion. In it is located the byssal gland that secretes the byssus by which the scallop attaches itself to eelgrass or other objects. Attachment is more common with juvenile scallops but sometimes is practiced by mature or nearly mature individuals. It is interesting to note that an European species, *P. varius*, retains the practice of byssal fixation throughout life and even moves about by renewing and slightly shifting the point of byssal attachment (Fischer, 1867). It has been suggested by Dakin (1909) and claimed by Uexküll (1912), for whom a rudimentary organ can not exist, that the deeply grooved, suckerlike tip of the foot is employed in the removal of foreign material from the shell. Certainly at times the foot is rather active for an organ the only function of which is the rare spinning of a byssus. In the very young it is, of course, used for locomotion (crawling).

ADDUCTOR MUSCLE

The adductor muscle (morphologically the posterior adductor) of the scallop (see figs. 3 and 11) is of special interest. The great size of this muscle renders economically feasible the practice followed in this country of utilizing it only, of all the tissue of the scallop. It is correlated with the unusual lamellibranch habit of swimming. The adductor of a very large scallop (89 millimeters long), taken in January, was found to weigh 20 grams after draining.

The adductor muscle is composed of two very unequal parts. The larger and clearer is the motor muscle which functions to snap the valves together and provides the motive power for swimming. In the scallops it is composed of striated fibers. The smaller, milky white portion, sometimes termed "ligament" by scallopers, which lies posterior to the larger and is composed of unstriated fibers, functions to hold the shell closed or in any partially closed position. It exhibits what has been known as the "catch mechanism" and, therefore, has been termed "catch muscle." If an object be thrust between the open valves, these close sharply upon it and hold. If then the object be pulled from between them, the valves temporarily remain as they were. Pressed closer together they remain in the new position a time but resist opening. Sometimes too forceful opening tears the catch muscle in two. These phenomena have been observed by me many times and are well known. To all appearances and in effect it is as if the muscle were not pulling the valves together but instead rigidly retaining them as by a catch, or better a ratchet, which does not interfere with shell closing, but against quick opening pressure is unyielding, unless "thrown out" by the proper nervous stimulus.

Such phenomena have attracted much attention. A very interesting account is that of Uexküll (1912), who reported that certain nerves inhibited the catch mechanism and others brought it into play, but that if the nerves were cut when the mechanism was in operation, stimulation of the nerve endings could not be made to throw out the catch. The smooth muscle remained at the length it had when the nerve was cut. Important earlier investigators were Pavlov (1885), Marceau (1909), and Parnas (1910). The latter failed to find evidence, as he believed, of increased metabolism with increased strain or exhaustion after prolonged strain. This, together with the remarkable ratchetlike functioning, made a good case for the view that this portion of the adductor might be considered as a passive mechanism under nervous control, not active muscle. This is most interestingly discussed by Bayliss (1918).

Increased information and renewed consideration of the evidence have led recent investigators to doubt the validity of the catch mechanism hypothesis. Ritchie (1928) reviews the published data and some unpublished work in which he shared. From the data on metabolism, relaxation time, tension, response to stimulation, etc., he comes to the conclusion that, while there are several doubtful points, there is nothing known which is incompatible with the view that catch muscle is merely very slow muscle of great tension (but not especially great in Pecten whose muscles instead are relatively fast). See also Boylan (1928), Waele (1927), and Hopkins (1930).

Although as the expression of an acceptable hypothesis "catch mechanism" and "catch muscle" may be doomed to be discarded, merely as a descriptive name "catch muscle" is effective and useful and may be retained.

CIRCULATORY SYSTEM

The circulatory system of the giant sea scallop, *Pecten tenuicostatus* or *Pecten grandis* (see p. 571) has been studied by Drew (1906) and that of *P. maximus* by Dakin (1909), with such close agreement as to path followed, except for the quite different gills, that it may be assumed that the circulation of *P. irradians* is very much like that of these forms. This assumption receives support from such observations as are readily made, as of the vascular network of the mantle and of the veins of the visceral mass. Circulation, therefore, may be summarized as follows: Blood leaves the ventricle by the anterior and posterior aortæ. The posterior aorta supplies the adductor muscle, the rectum, and, through the large posterior pallial artery and the circumpallial artery, the mantle. The anterior aorta supplies the remainder of the body and, through the anterior pallial artery, contributes blood to the circumpallial artery. Blood from the mantle, after passing through a net work, returns directly to the heart. According to Dakin the venous system consists largely of sinuses (see fig. 12b), contrasting with the definite vessels of the arterial system. Large sinuses between the adductor and its sheath and paired veins from the visceral mass and digestive diverticula convey venus blood to the kidneys, which receive all the blood except that of the mantle. From the kidneys the blood passes to the gills and thence to the heart. Figure 12, after Dakin, shows the main arterial and venous circulation except for the mantle and gills.

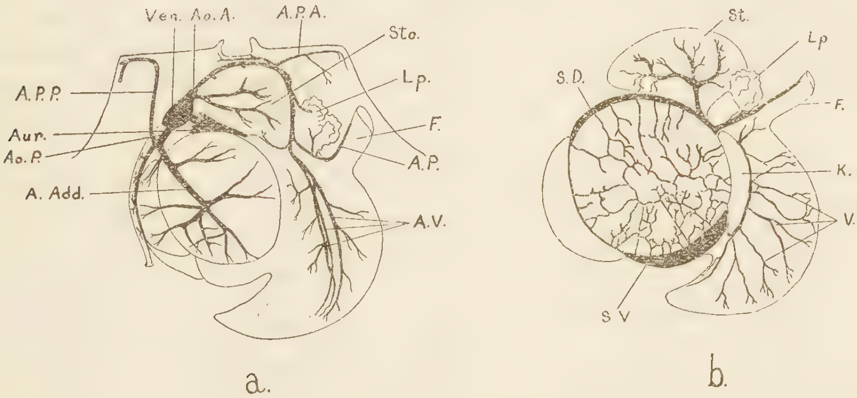

FIGURE 12.—Main vascular circulation, except for mantle and gills (after Dakin): *a*, Arterial circulation; *b*, venous luriccation; *A. P. A.*, anterior pallial artery. *A. P. P.*, posterior pallial artery; *A. Add.*, adductor; *Ao. A*, anterior aorta; *Ao. P*, posterior aorta; *A. P.*, pedal artery; *Aur.*, right auricle; *A. V.*, visceral arteries; *F*, foot; *K.*, kidney; *Lp.*, lips; *S. D.*, dorsal venous sinus; *St.*, tissue surrounding the stomach; *S. V.*, ventral venous sinus; *V. V.*, viscereal veins

The symmetrical heart consists of two auricles and one ventricle. The auricles are relatively large and very uneven of surface. The ventricle, traversed by the rectum, is greatly reduced in size when contracted and is smooth exteriorly. Drew described muscles around the openings of the auricles which he believed acted as sphincters to prevent the back flow of blood from the ventricle. The firm walled, triangular pericardium lies in the angle formed by the posterio-ventral surface of stomach and digestive diverticula, on the one hand, and the dorsal surface of the adductor muscle on the other. It extends from one pallial lobe to the other.

NERVOUS SYSTEM AND SENSE ORGANS

The nervous system (fig. 13) comprises a central nervous system of three pairs of principal ganglia with commissures and connectives and, in the ganglionic circumpallial nerve, what might be termed a peripheral nervous system. (See Boutan, 1902, and under "Mantle" in this paper.)

The three pairs of central ganglia are considerably modified in arrangement. The cerebral ganglia are closely united with the pedal ganglia, which are joined one to the other without appreciable commissure. (Fig. 14.) The visceral ganglia are so fused and developed that they form one large, complex, ganglionic mass (fig. 14) and warrant the term visceral ganglion adopted by Dakin (1910).

The elongate, slightly bilobed, cerebral ganglia are located near the surface between lips and foot. At the anterio-dorsal end of each arises the cerebral commissure which passes dorsally in a loop around the oesophagus and connects the paired ganglia. From the other end extends the large cerebro-visceral connective. Near the middle of the outer side three nerves arise together. The first, or innermost, is small and leads to the "tufted" lips and may be termed the "labial nerve." The larger, middle one, the anterior pallial nerve, sends two branches to the circumpallial nerve. The outer one supplies the palps and is here termed "palpal nerve." In some instances the anterior pallial and the palpal nerves continue as one for a short distance before separating. The fine otocystic nerve of each of these ganglia arises near the source of the cerebro-pedal connective and leads away from the surface to a small round otocyst, from which arises a threadlike structure termed the otocystic canal. For histological detail see Buddenbrock (1915) as to Pecten and Field (1922) as to Mytilus. For accounts of the importance of the otocysts as organs of balance and control of movement see Buddenbrock (1911 and 1915). They have also been considered organs of hearing. The cerebral commissure extends around the œsophagus.

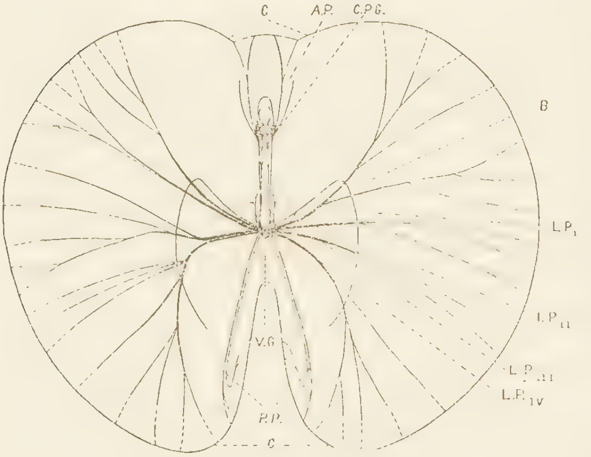

FIGURE 13.—Interior view of nervous system. *A. P.*, Anterior pallial nerve; *B.*, branchial nerve; *C.*, circumpallial nerve; *C. P. G.*, cerebropedal ganglia; *L. P. i-iv*, lateral pallial nerves; *P. P.*, posterior pallial nerves; *V. G.*, visceral ganglion. The lettered side is the left side

Between the two cerebral ganglia, and connecting them, lie the abutting pedal ganglia and the short cerebro-pedal connectives, one of which arises not far from the center of the inner side of each cerebral ganglion. From the pedal ganglia arise the pedal nerves which enter the foot, subdivide, and become much convoluted.

The large cerebro-visceral connectives lead diagonally along the stomach and midgut to the adductor muscle and thence to the visceral ganglion which lies on the anterio-ventral surface of this muscle, between it and the visceral mass, but extending chiefly to the right so that a large part may be viewed without dissecting away the visceral mass. In size, complexity of shape, and number and size of nerves which arise from it, the visceral ganglion greatly exceed any of the other central ganglia.

(See fig. 14.) The lateral pallial nerves which arise under the lateral lobes, that is, between the ganglia and the adductor muscle, pass principally ventral of the kidneys along the sheath of the adductor muscle and (on the right side) the support of the branchial axis to the mantle and spread through it (fig. 13) to the circumpallial nerves. Posterio-ventrally to the lateral, arise the posterior pallial nerves which join with the circumpallial nerve near the posterior end of the hinge. Each of the two branchial nerves has a double origin. One of these lies under the lateral lobe, anterio-dorsal of the lateral pallial nerves, the other on the surface of the central portion of the ganglionic mass between a lateral lobe and the central lobe. These roots of the branchial nerves are cross connected near the base. They pass along the ventro-lateral edges of the kidneys and thence to the branchial axes and along them to the tips. For a more detailed study of the visceral ganglion and the nerves arising therein see Dakin (1910).

Where a cerebro-visceral connective joins the visceral ganglion there arises, on each side, a small body which corresponds to the "swelling" of Drew (1906) and the accessory ganglion of Dakin (1910). Each of these bodies is connected with the branchial nerve near its base and at the tip gives off three branches. One of these parallels for a considerable distance a cerebro-visceral connective. Another, developing several obvious branches, extends somewhat dorsally toward the anterio-ventral surface of the visceral mass. The third extends into the overlying tissue of the visceral mass (ovary, etc.), and, according not only to several dissections but also to observation of material cleared in glycerin, joins its fellow from the other side. (Fig. 14.) Thus these bodies or accessory ganglia supply various portions of the visceral mass and are interconnected through a structure apparently not heretofore observed.

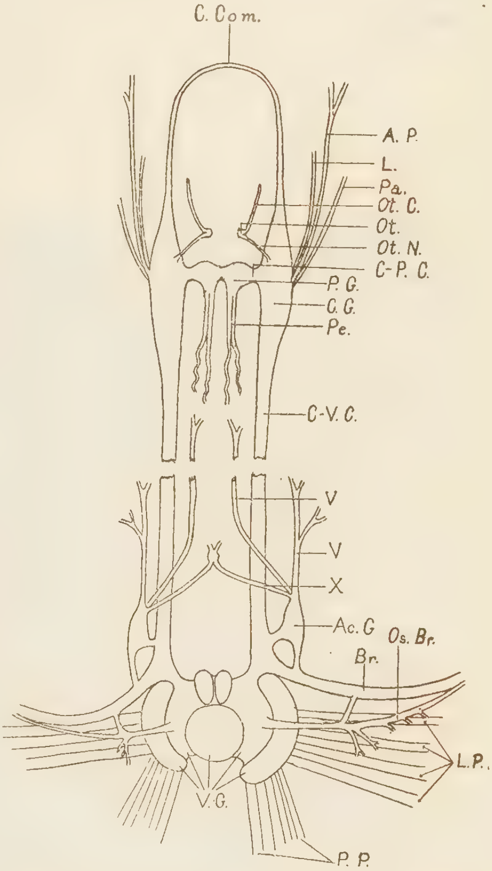

FIGURE 14.—Central nervous system. *Ac. G.*, Accessory ganglion; *A. P.*, anterior pallial nerve; *Br.*, branchial nerve; *C. Com.*, cerebral commissure; *C. G.*, cerebral ganglion; *C–P. C.*, cerebro-pedal connective; *C–V. C.*, cerebro-visceral connective; *L.*, nerve to tufted lips; *L. P.*, lateral pallial nerves; *Os. Br.*, osphradio-branchial nerve; *Ot.*, otocyst; *Ot. C.*, otocystic canal; *Ot. N.*, otocystic nerve; *Pa.*, palpal nerve; *Pe.*, pedal nerve; *P. G.*, pedal ganglion; *P. P.*, posterior pallial nerve; *V.*, nerve of the visceral mass; *V. G.*, visceral ganglion (with crescentic "lateral lobes" and central portion with large globular "ventro-central lobe" and paired "dorso-central lobes"); and *X.*, structure of unknown designation

The abdominal sense organ (Dakin, 1909 and 1910) is to be found on the edge of a connective-tissue flap near the right pallial lobe. It is small, elongate, somewhat brownish, and covered with a dense mat of fibers. Dakin (1910) was unable to find any effect made by its removal or "stimulation." Without supporting evidence, various functions, such as water testing and detection of movements in the water, have been attributed to it.

The osphradia of Pecten are very inconspicuous structures and, in these investigations, have not been positively observed. The osphradial branches of the osphradio-branchial nerves arise just ventral to the kidneys. (See fig. 14.) Dakin (1910) found no evidence of an olfactory or other sense in these organs of Pecten. On the other hand Copeland (1918) found that certain predacious gastropods responded definitely to olfactory stimuli but failed to respond after the osphradium had been removed.

The eyes and tentacles have been described with the mantle.

URINOGENITAL SYSTEM

The urinogenital system comprises ovaries, testes, pericardium, and kidneys.

The ovaries are located in the ventral or tip portion of the visceral mass and are, when eggs are present, pink or even red. The white or cream colored testes occupy that portion of the mass dorsal to the ovaries and ventral to the stomach and also extend, anterior to the mid-gut, along the outer edge of the mass well toward the tip. Occasionally "islands" of ovarian tissue are to be found within the limits of the testes, and vice versa. Rarely organs of one sex are so greatly extended as to make the individual appear unisexual. The general position of ovaries and testes is shown in Figures 10 and 11, and something of the microscopical structure of an ovary in Figure 15.

Credit for the discovery that the sexual organs of Pecten open through the kidney is given to Garner (1841). Lacaza-Duthiers (1854) figured a common duct to take both eggs and sperms to the kidney, through which they are discharged. The passages are somewhat hard to follow, but have been traced by Dakin in serial sections and demonstrated by gently pressing the ripe gonads so that masses of eggs or sperms are seen to emerge from the kidney.

The renal organs, or kidneys, are asymmetrical lozenge-shaped organs, generally light brown in color and located on the adductor muscle (figs. 4 and 11), one on each side of the visceral mass in the angle formed with the branchial axis. They are well supplied with blood vessels. The lumen is much branched. The walls are glandular (see Kellogg, 1892; Drew, 1906; Dakin, 1909) and ciliated (but see Dakin, loc. cit.). Urea is given off in solid concretions (Pelseneer, 1906) which have been figured for *P. irradians* by Kellogg (1892). An elongate, lipped urinogenital aperture is located at the ventral end of each kidney, near the visceral ganglia. Dakin states that the two kidneys communicate one with the other at their dorsal ends through a transverse duct lying between the visceral mass and the adductor muscle.

It seems to be well demonstrated that the pericardium communicates with each of the kidneys and forms part of the excretory system (Pelseneer, 1906; Drew, 1906; Dakin, 1909). I have failed to find the reno-pericardial openings in *P. irradians* or even to demonstrate them by means of red pericardial injections. In some instances a red kidney was thus obtained, but in no instance did the red fluid appear at the urinogenital aperture, which is taken to mean that in some manner the blood spaces of the kidney received the injection. Although Drew apparently found the openings without difficulty in the large sea scallop, Dakin failed to demonstrate them by injecting the kidneys and was only able to make them out by serial sectioning. In the case of the scallop the excretory function of the pericardium is stated to be carried out by the walls of the auricles, which are uneven, somewhat spongy, and of a yellow color.

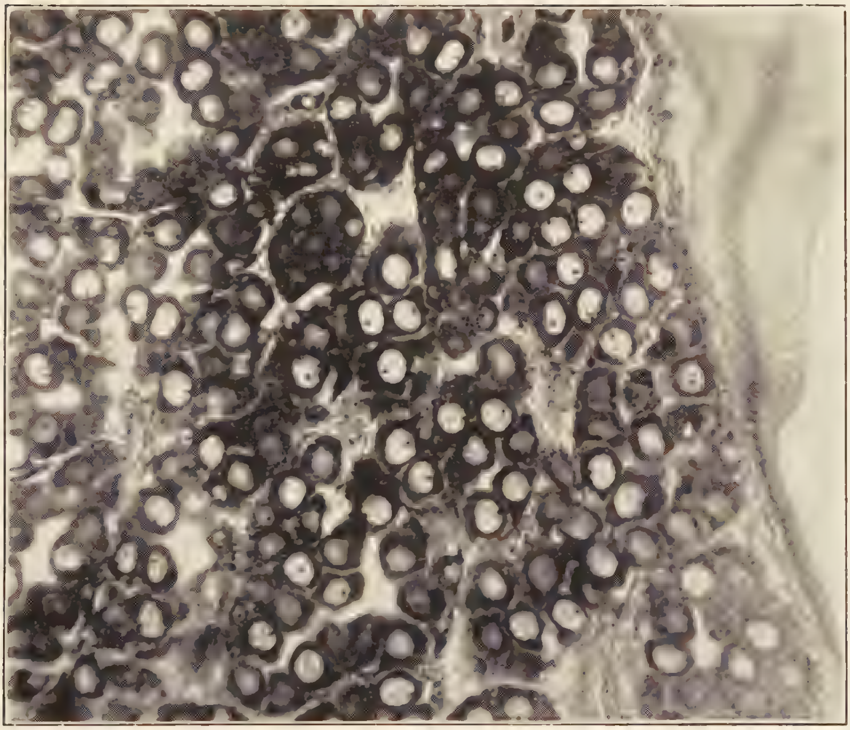

Figure 15.—Photomicrograph of portion of ovary of scallop collected at Pivers Island, November 11, 1925. Mature or nearly mature eggs abundant. Small immature eggs also shown. Magnified 125 times. Larger eggs measured 0.055–0.065 millimeter in major diameter. Bouin's fixation and iron hæmatoxylin

FEEDING

The principal organs for securing food, as previously noted, are the gills. For the scallop, as for some other forms, it seems clear that under certain conditions of feeding, as when much sediment is present in the water, they also enter into the process of selection (acceptance or rejection of filtered particles). For a description of the feeding currents and the location and functions of the various ciliated tracts see under "Gills." Here it need only be noted that the gills bring in the food-laden water, separate food organisms and other particles from it, and convey these to the palps. The palps, as described by Kellogg (1910, 1915) and various workers, through the action of a complex and often puzzling arrangements of ciliary currents either pass the material to the lateral opening between the tufted lips or, if it be too coarse or in too large masses, through muscular action bring reverse currents against it and thus cast it away, near the foot, to be ejected near the byssal notch.

Material not rejected passes into the transverse tube formed by the interlocking tufted lips, thence into the œsophagus, and thence, still by the action of cilia, into the stomach, where it again meets complex ciliation further complicated by the action of the style.

No special study has been made of the food of the bay scallop. Apparently it does not differ greatly from that of other lamellibranchs in similar habitats and consists chiefly of the available plant and animal plankton of suitable size and shape, with nannoplankton playing an important part, and includes considerable quantities of the free moving microflora and microfauna of the bottom. In the relatively small number of stomachs examined by me, detritus sometimes bulked large, but whether it is important as food is not certain. Peterson and Jensen (1911) believed such material to be of greatest importance for the oyster. More recently Martin (1923), Hunt (1925), Savage (1925), and Yonge (1926a) have questioned the ability of lamellibranchs to digest detritus such as that formed from Zostera and believed to constitute the larger portion of the organic content of coastal waters. Hunt (loc. cit.) found that the stomach contents of *P. opercularis*, from deep water, generally reflected the nature and variation of the plankton. Peridinians were especially abundant in the stomachs during late spring and summer, diatoms (important at all times) during fall and winter.

CILIARY CURRENTS OF MANTLE, VISCERAL MASS, ETC.

The ciliation of the mantle and other surfaces within the pallial cavity has been figured by Kellogg (1915) who studied both *P. irradians* and the sea scallop, *P. grandis* Solander (*P. tenuicostatus* Mighels of Drew and Kellogg). In general my observations are in agreement with his. (Fig. 16*a*.) However, I found currents on the visceral mass of the bay scallop differing considerably from those shown by him for the sea scallop (compare 18*b* with 18*c*). These various ciliary currents convey material deposited upon them to points where it will be ejected with the feces or with material rejected by the palps.

PIGMENTATION OF THE VISCERAL MASS

If normally active scallops are opened and examined, the pendant visceral mass, tufted lips, and the outer surface of the palps are found to be more or less highly pigmented (as indicated in part by Fig. 3). This pigmentation varies greatly in intensity, but is always marked on the visceral mass except in "poor" or weak individuals or adults kept long in the aquarium, with which it is always very pale or wanting. The color varies from light green almost to black. Indeed frequently the visceral mass of juvenile scallops might fairly be termed black.

Overlying the gonads and surrounding the visceral mass is a tough transparent membrane. This may be so removed as to retain the epithelium, spread in sea water on a slide, covered with a slip, and examined under high magnification (3 millimeters water immersion). It thus appears that the coloring is due to granules of two colors grouped in the epithelial cells. Some granules are yellow, others dark. Under the microscope these darker granules sometimes appear decidedly blue but may be green. It can be seen that some cells contain only the lighter granules. Others appear to contain only the darker ones. Some cells, even in darkly colored areas, are almost devoid of colored granules.

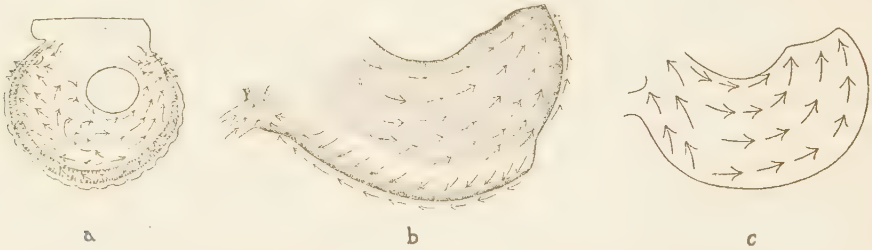

FIGURE 16.—Ciliary currents of mantle and visceral mass; *a*, right pallial lobe (after Kellogg); *b*, left side of visceral mass with base of foot shown at left and pigmentation represented by stippling (from observations on the movement of fine carborundum); *c*, ciliary currents of visceral mass of *P. tenuicostatus* (after Kellogg)

Fixed and preserved material does not retain the greenish color, appearing brown instead, but has the advantage that it may be sectioned and a different view of the epithelium obtained. In sections cut at right angles to the surface, the disto-proximal arrangement of the granules in the epithelial cells may be seen. Although distinct color difference has been lost, dark and light pigmentation may still be observed. As shown in Figure 17 the granules, particularly the dark granules, lie principally near the outer surface of the epithelium.

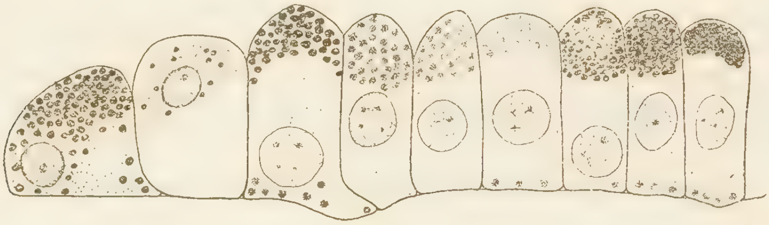

FIGURE 17.—Pigmented epithelium of the visceral mass (from material fixed in Bouin's)

Because of the evident and unfailing loss or great reduction of this bodily coloration with scallops in poor condition, the writer suggests that the pigmentation is connected in an important way with feeding or metabolism.

SWIMMING

A swimming scallop has been well likened to a bellows; the valves corresponding to the bellows boards, the velar folds or curtain to the leather sides or "bellows," and the anterior and posterior velar openings to the nozzle. The valves are opened and forcibly closed. As the closing starts the velar folds of the two mantle lobes are brought together to form a wall or curtain which prevents egress of the water except dorso-anteriorly and dorso-posteriorly through the gaps near the hinge. (See fig. 18.) The jets through these openings send the scallop in the opposite direction; that is, ventrally with the free margin of the valves in advance and tilted upward even when progression is horizontal, as along the surface, as though the animal were biting its way through the water.

Nearly all accounts agree on the means of progression. As to the manner, however, there is some difference. Jackson (1890) stated that the jets are alternately through the dorso-anterior and dorso-posterior openings, thus causing an alternate rotation through 90° or more and resulting in an extremely zigzag course. This does not agree with my observations. As previously noted the account of Jackson seems to have been unhesitatingly followed by American writers.

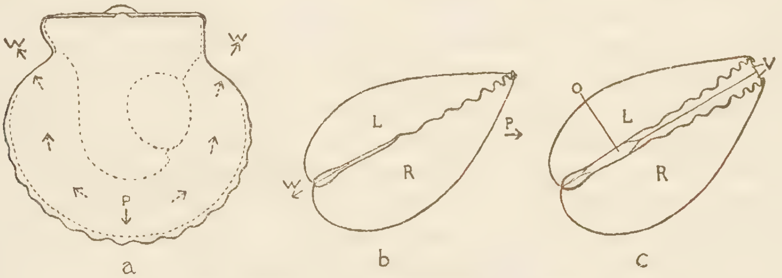

FIGURE 18.—Diagrammatic sketches of scallop swimming: *a*, As seen from above and at right angles to the plane of the valves and showing, in dotted lines and arrows, the water channels as bounded centrally by visceral mass, branchial axes, adductor muscle, etc., and peripherally by velar folds; *b*, anterior view at end of "power stroke" (shell closing), showing tilting of shell (angle not determined); *c*, anterior view, early part of "power stroke"; *L*, left valve; *O*, opening for emission of propulsive jets; *P*, direction of progression; *R*, right valve; *V*, velar folds united to form a wall or curtain which is continuous except near each end of hinge; *W*, propulsive water jet

Jackson, who worked with *P. irradians*, stated that early in the shell closing there is a ventral egress of water before the edges of the velar folds come together. Anthony (1906) and Dakin (1909), working with Eurpoean scallops, stated that the juxtaposition is timed to prevent such water movement. This is somewhat difficult to determine. Apparently at times, with our species, there is such egress, at least at the first clap or power "stroke," for which the valves may be more widely separated than for later ones.

Steering according to Dakin is effected by a partial closing of one or the other of the velar gaps, according to Buddenbrock and to Uexküll also, and more accurately, by slight local separations of the edges of the velar folds.

Besides normal swimming there have been described various sorts of scallop movement.

Under special circumstances the scallop forces out the water ventrally and darts hinge foremost along the bottom. This has been described by Anthony (1906), Dakin (1909), Belding (1910), Buddenbrock (1911), and Uexküll (1912). Belding, working with small, juvenile scallops, found that it occurred if one of these was approached ventrally with the point of a pencil and evidently was for the purpose of taking the scallop away from the pencil. Anthony, Buddenbrock, and Uexküll attributed this movement to a direct local stimulus. Dakin found the cause in sudden stimulation. I have observed this "backward" darting, especially when a scallop was touched suddenly, but, working with mature or nearly mature individuals kept in captivity, have not been able to induce it at will by mechanical stimulation. It seems to be in part a startled movement but I have induced it by repeated chemical stimulation of the midventral portion of the mantle margin.

According to Dakin and Buddenbrock this reversal in direction of progression is due to an indrawing of the velar fold during shell closing, according to Anthony and Uexküll to a local contraction of this structure which is so important for swimming. If this latter explanation is correct it is strange that the darting, according to all these accounts and in so far as I have noticed, is always hinge foremost and not sometimes hinge sidewise or diagonally.

A third type of movement described by various investigators (for example Dakin, Buddenbrock, and Uexküll) is that by which a scallop turns over after being placed wrong side up. This is performed by arranging the velar folds, along the ventral margin of the shell, so that when the valves are forcibly brought together, a stream of water is directed downward against the bottom. This lifts that edge of the shell and turns the scallop right side down. Belding (1910) states that the turning ordinarily is forward or backward. With local, adult specimens the turning is somewhat difficult to study, for scallops so placed (contrary to the experience of Grave (1909)) may remain wrong side up for hours, and indeed have been found, although rarely, in this position on the flats. It seems probable that scallops of this species lie so nearly universally in the normal position principally because they settle on the right side after swimming, which is with the left side up. As previously noted, Buddenbrock (1915) found that Pecten may also right itself around an axis perpendicular to the hinge line.

Jackson (1890) described a sort of "scuttling" movement over the bottom produced by repeatedly expelling water through one velar gap only.

Anthony (1906) noted that a scallop may rotate horizontally by a single, moderate contraction which drives the water between the velar folds at one point only.

Although scallops have been supposed to shift considerably and even to make distinct migrations, field observations indicate that during a large portion of the scallop's life shifting ordinarily, in local waters, is very slight. Not only do near-by flats yield scallops of different size or shape but, in some instances, different portions of a large flat yield scallops notably different in size. Thus, in western Bogue Sound, scallops of good size were found along the edge of the dredged channel north of Lovetts marsh. A few rods away from the channel scallops were of the diminutive size usual in this section of the sound. Other instances have been noted. Indeed it seems probable that shifting, except as the vegetation to which the young scallops cling becomes detached and is carried away by wind or tide, is slight after the veliger stage is passed.

REPRODUCTION AND DEVELOPMENT

SPAWNING PERIOD

A knowledge of the spawning period of a species may be important for various reasons. For a commercial form it often is essential for conservation (as by legal regulations). Much of the life history and biology must remain obscure until this period is determined, at least in part. It may be of considerable theoretical interest. For the bay scallop all of these apply.

A spawning period may be determined in various ways. It may be possible to determine it, at least in part, by direct observation or by watching the animal spawn. By examination of the gonads and noting when they first show ripe sexual products, first show evidence of discharge of sexual products, and when the gonads become emptied, the beginning and end of the period may be determined. However, to learn the time of principal and effective spawning, it generally is necessary systematically to collect eggs, larvæ, or young, noting when these first appear in numbers, become abundant, decrease and disappear.

Some information was obtained by the first two methods. Seldom is it practicable to collect lamellibranch eggs. For reasons that will be discussed later, collections for larvæ gave little aid. By far the best evidence as to principal time of spawning came from collections for small scallops beyond the larval stage.

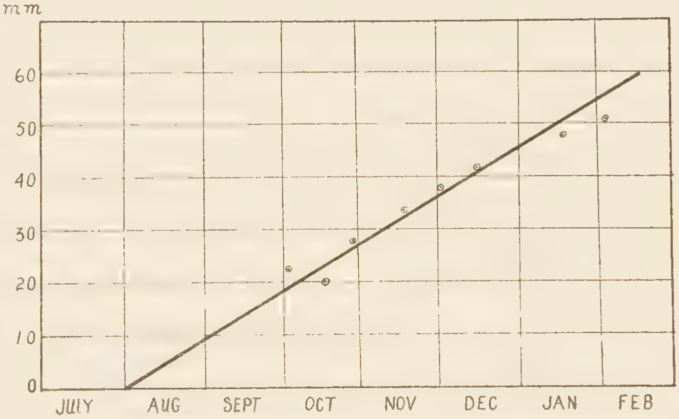

FIGURE 19.—Graph based on largest scallops of 1926 year class obtained during fall of 1926 and a portion of succeeding winter. The junction of trend with base line was taken to indicate approximately the beginning of spawning

In North Carolina very small scallops seldom, if ever, become so numerous as to be in evidence amidst the vegetation to which they attach, and it was not till the fall of 1926 that methods were developed which gave satisfactory data as to their abundance. The method consisted in collecting and drying a tub of eelgrass and other vegetation from the flats, screening the siftings from the vegetation, and examining the screenings for scallops. The material retained by the finer screen was examined under a binocular. At that time young of the year already had attained considerable size. Very small scallops continued to be found abundantly until February 2, 1927, decreased in March, and became rare in April. (See fig. 20.) Although the age of these small scallops was not definitely known, from consideration of growth rate and from observations on scallop gonads, it was concluded that important spawning continued into January. An attempt was then made to determine the beginning of spawning. From semimonthly size-frequency curves (5 millimeter groupings) the "first appearance" of scallops in succeeding size groups was noted.

These "size dates" were then plotted to represent the growth of the oldest scallops of the year's (1926) spawning and were found to lie reasonably close to a straight line. (Fig. 19.) The junction of this line (growth curve) with the base line was taken to indicate a beginning of spawning by late July or early August. Although it was realized that linear growth would scarcely be truly uniform, with such notable change of size and season, it was thought that the "indication" might be sufficiently close to be helpful.

Small scallops reappeared in the grass collections in June and continued through July, but without any evident increase and in such small numbers as to mean little. With the first August collection, however, a marked change occurred. Small scallops were present in numbers which indeed were small compared with those of the fall, but large compared with those obtained since the disappearance months before. Increased numbers were obtained later in the month and impressive numbers early in September. The spawning period evidently began in July and became rather important in August and, therefore, is an affair of late summer, fall, and early winter, but chiefly of the fall. (See Table 3 and fig. 20.) Spawning has been obtained experimentally as early as August 26.

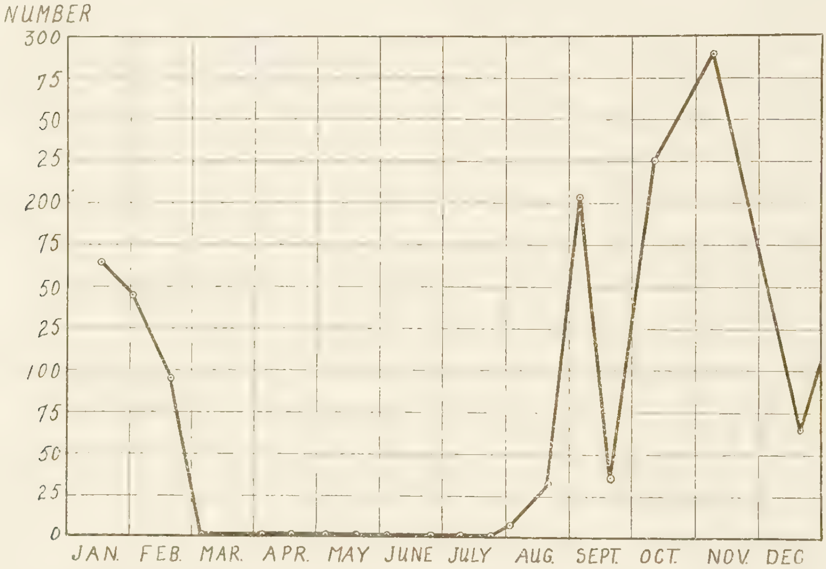

FIGURE 20.—Spawning as indicated by the abundance, through 1927 collections, of scallops 2 millimeters or less in length. (See Table 3)

This has affected the writer's recommendations for conservational regulation (Gutsell, 1928). Because various bivalves, and in the north the bay scallop, spawn during the period when water is warming, and indeed seem to depend upon a temperature rise for a spawning stimulus, the fact that scallop spawning here occurs principally while temperatures are dropping is of considerable interest.

The long-continued season explains the lack of a period of extreme abundance of very young scallops in highly productive areas.

TABLE 3.—*Numbers of scallops 2 millimeters or less in length taken in the various "grass" collections at Pivers Island from January, 1927, to January, 1928*

[When one collection was made during a period of 3 or 4 days, a central date is given. (See fig. 20.)]

Date	Number	Date	Number	Date	Number
1927		1927		1927	
Jan. 17	164	May 19	0	Sept. 20	37
Feb. 1	140	June 3	1	Oct. 11	227
Feb. 19	92	June 25	1	Nov. 9	289
Mar. 5	2	July 8	1	Dec. 23	66
Mar. 20	2	July 23	1		
Apr. 4	0	Aug. 2	8	1928	
Apr. 18	0	Aug. 22	43	Jan. 25	216
May 4	0	Sept. 6	204		

SPAWNING

As previously noted, the ovary and testis for each side open through a common duct into the kidney of that side, and thence through the urinogenital opening into the suprabranchial space, with its exhalant current. Eggs, pink or almost red in mass, and sperms, white or cream, supposedly and apparently are discharged separately to the exterior so that self-fertilization is the exception. Self-fertilization has been obtained experimentally by Risser (1901), Belding, and the writer under artificial conditions. Certain observations of Kellogg suggest that frequently a small number of eggs may be self-fertilized under natural conditions, for Kellogg (1892) frequently found a few developing eggs in the kidneys. It seems more probable that these were fertilized either in the kidney or in the common gono-duct by sperms emerging through the same passage than by entering sperms from another individual. Belding has noted in rare cases a simultaneous discharge of eggs and sperms.

Belding (1910) induced spawning by transferring scallops from relatively cool water to jars of water placed in the sun to warm. Risser (1901) and Drew (1906) confined scallops ready to spawn so that these investigators might obtain eggs and sperms, but seem not to have attempted to induce spawning. I made many attempts to apply Belding's method, but failed so frequently as to suggest that temperature rise is not a very effective stimulus to spawning, which would not be surprising in a region where scallop spawning occurs principally during a period when water temperature is declining. An alternative explanation is that the extended spawning season gives relatively small chance of finding scallops just ready to spawn.

As previously noted, spawning was obtained as early as August 26. Two scallops were placed in separate bowls of water at 25° C. Sea water heated in a flask, closed except for a condenser tube, was added to these bowls until the temperature was raised in one case first to 28.5° C., and then to 32° C., in the other case, first to 29.5° C. and then to 30.5° C. When in a few minutes the water which had stood at 32° C. dropped to 30° C., the scallop in that bowl began to spawn, casting out both sperms and eggs, many of the latter in small chunks and apparently not fully matured. "Self-fertilization" occurred and in 1 hour and 20 minutes 3-celled (or possibly 2-celled with yolk lobe) embryos were numerous.

From this experiment vast numbers of embryos were obtained. In one day most of these were in the gastrula stage, in two days either in the trochophore stage, or with shells developed. Some of the shelled larvæ remained alive six days but made little growth.

Numerous similar attempts were made (a close following of Belding's method having uniformly failed), generally with poor or no success. If eggs were obtained sperms would not be obtained or would not fertilize the eggs.

Once some success was obtained accidentally. A scallop out of water, being measured, squirted out about a quarter of a teaspoon of pink eggs. This scallop was placed in a bowl of sea water where it continued to emit vast numbers of eggs. Three other scallops were placed in separate bowls. These cast sperms. Water in which the sperms were most active was poured into that containing eggs. Larvæ from this lot lived to be 3 days old.

Although scallops sometimes, particularly late in the season, discharge a large portion of their sexual products in a brief time, from observations of the gonads it appears that in North Carolina individuals ordinarily spawn over a considerable period.. This is in accord with the observations of Belding (1910).

FERTILIZATION AND EMBRYONIC DEVELOPMENT

Fertilization normally is external and consists in the union of the small, active sperm with the egg. Testicular sperms which appear mature are about 0.05 millimeter long, with heads 0.001 to 0.0012 millimeter long. These dimensions are considerably different from those shown by Belding (1910) for cast sperms (length about 0.07 millimeter, head about 0.0006). Ovarian eggs may be about 0.063 by 0.06 millimeter (sample measurement), but with shape varying. These measurements correspond well with Belding's scale drawings of cast eggs. The sperms swim until they come in contact with an egg (or perish), about one of which great numbers may cluster with heads toward the egg. Normally only one enters (see Belding, 1910), fertilization occurs, and development begins.

Scallop embryology has been studied by Fullarton (1890), Drew (1906), and Belding (loc. cit.) and is included in the general statement of Korschelt (1900). Embryonic development is of the typical lamellibranch type with unequal cleavage and without blastula. (See fig. 21.) A yolk lobe which resembles a micromere, appearing before the second micromere and later absorbed by the macromere, is described and figured by Belding and Drew. The gastrula is epibolic. At this stage the embryo is well supplied with cilia and rolls about in the water. Belding obtained this stage in about 10 hours. Next a trochophore is formed. Belding obtained this stage in 12 to 14 hours, but the writer not so quickly (from about 1 to nearly 2 days at about 25° C.). This takes the scallop through the embryonic into the larval stage.

LARVAL DEVELOPMENT

The earliest larva (fig. 21), termed the trochophore (or trochosphere) from its resemblance to the annelid larva of the same name, possesses besides shorter cilia, a flagellum which appears to be single but has been found (Belding, 1910) to be a close tuft of as many as six large cilia. A primitive digestive tract is present. At this stage the animal swims forward (flagellum in advance) and rotates.

Following the trochophore comes the veliger with its velum and with an alimentary canal in which œsophagus, stomach, and intestine have been described. Soon after the formation of the velum, a shell (the prodissoconch) appears and quickly increases to cover the animal. Swimming is by the beating of the cilia of the velum (aptly termed propeller by one waterman). The shell is of the type known as straight-hinged, although the hinge line really is concave. (Fig. 21*h*.) Belding obtained this stage in 17–40 hours, the writer in 42–48 hours at about 25° C. The anatomy of the early veliger, including early shelled larvæ, was figured in considerable detail by Belding. Besides the structures mentioned, anterior adductor and velum retractor muscles are shown.

Beyond an early "straight-hinged" stage Belding did not succeed in rearing the larvæ nor, among the forms taken in the plankton net, was he able to recognize later stages, short of the fully developed prodissoconch. This stage he figured in considerable detail, showing it as about 0.18 millimeter long and with the left valve decidedly larger.

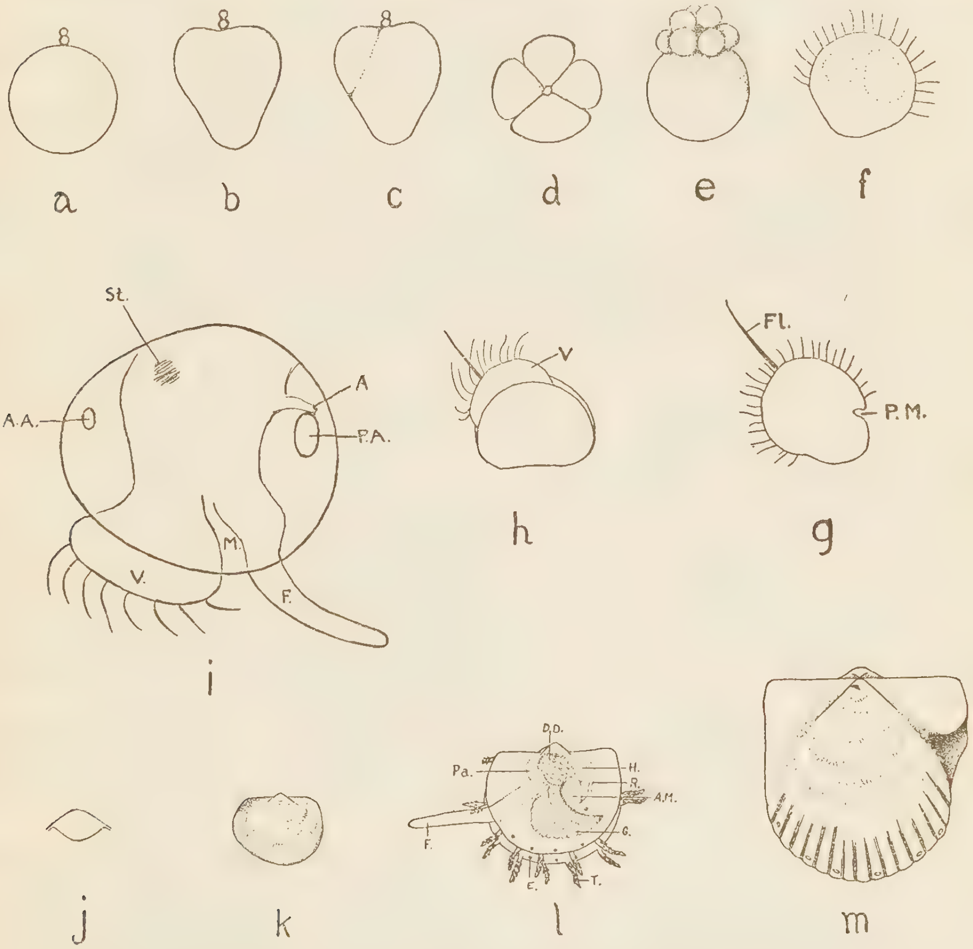

FIGURE 21.—Early development: *a*, Polar bodies formed at animal pole; *b*, yoke lobe formed at vegetative pole; *c*, first cleavage; *d*, 4-cell stage; *e*, 8-cell stage; *f*, ciliated gastrula; (*a–f*, embryonic stages); *g*, trochophore (*a–g*, after Belding); *h*, early veliger or prodissoconch, about 0.08 millimeter long; late prodissoconch, about 0.18 millimeter long (*g–i*, larval stages, see text); *j*, longisection of very early postlarva about 0.22 millimeter long, showing asymmetrical, nepionic shell growth; *k*, length 0.54 millimeter; *l*, length 1.2 millimeters (*j–l*, nepionic stages); *m*, transition stage, 1.6 millimeters long, showing byssal notch and teeth, ribs, and overhanging large umbo of left valve (drawn with right valve uppermost). Structures: *A*, Anus; *A. A.*, anterior adductor muscle; *A. M.*, adductor (posterior) muscle; *D. D.*, digestive diverticula; *E*, eye, one of six shown; *F.*, foot; *Fl.*, flagellum; *G.*, gill; *H.*, heart; *M*, mouth; *Pa.*, palps; *P. A.*, posterior adductor muscle; *P. M.*, primitive mouth; *R.*, rectum; *St.*, revolving stomach contents presumably turned by style; *T.*, tenacles; *V.*, velum

My own attempts to rear the larvæ did not take them beyond the straight-hinge stage even though they remained alive in this stage for several days. From examination of the shells of small scallops, it appeared that the fully developed prodissoconch shell was about 0.18 millimeter long and inequivalve with the left valve the larger as stated by Belding but differing from the adult, which has the right valve the larger.

Accordingly inequivalve larvæ were sought in plankton collections. Two such larvæ were found. One of these was easily recognized as that of *Ostrea virginica*, the common oyster of commerce. The other, which proved to be the larva of the interesting oyster discovered at Beaufort (Gutsell, 1926) and identified as *O. equestris*, attained a size much too large for the scallop. To this day, except for a few Anomia, only these two markedly inequivalve larvæ have been found.

Finally, late in the fall of 1927, attention was drawn to a larva with equal valves but with a shell outline suggestive of that of the prodissoconch to be seen at the umbos of postlarval scallops. This larva did not markedly exceed the size of such prodissoconch shells and, after careful comparison, was tentatively accepted as the larval scallop. Later there was received the "Report of Experimental Shellfish Station" (Wells, 1927) with two plates showing the larval development of the bay scallop. One of these plates (see fig. 22) consists of excellent photographs, one of which shows individuals with an early postlarval shell growth and beginning to assume the secondary straight hinge of the adult scallop. The photographs indicate, but do not conclusively demonstrate, an equivalve larval shell. In correspondence the author states that the larval shell is equivalve. The shell outline is that of the Beaufort form taken to be the scallop.

Mr. Wells kindly furnished some material including larvæ, like mine too poorly preserved to be helpful, and also some very early postlarvæ. Examination of these latter revealed a curious asymmetry of the postlarval growth. (Fig. 21*j*.) This tends to make the left prodissoconch valve appear the larger and probably is sufficient explanation of the semblance, with later dissoconchs, of prodissoconch asymmetry. It does not, however, explain Belding's statement, based on examination of prodissoconchs, that the left valve of the late scallop prodissoconch is the larger.

In plankton collections, the equivalve larva assumed to be that of the scallop was taken during the scallop-spawning season and in the year when the "set" failed (1928) disappeared early in the spawning season. There seems little reason to doubt that it is the scallop larva.

In a form which is to have the right valve the deeper, the temporary deepening of the left valve is a curious phenomenon. In this connection it is interesting to note that although all scallops normally rest on the right side, some, *P. opercularis* (Dakin, 1909), and our giant sea scallop of commerce have the left valve the deeper. The thought that the temporary deepening of the left valve of the postveliger shell is philogenetic therefore suggests itself.

Belding figured the fully developed prodissoconch as without velum or anterior adductor, but with large (posterior) adductor, gills, large foot, rather complex alimentary canal, and an otocyst. He supposed that the velum disappeared as the foot was developed, so that by the time the foot was "perfectly developed" the velum had disappeared.

My sketches of living specimens (see fig. 21*i*) of the larva which I consider to be Pecten show both foot and velum present in specimens 0.18 millimeter long which is nearly as large as were obtained. What was taken to be the anterior adductor was noted in specimens at least up to 0.16 millimeter long, so that it seems probable that this structure continues to the close of the larval (prodissoconch) stage. Gills were not noted.

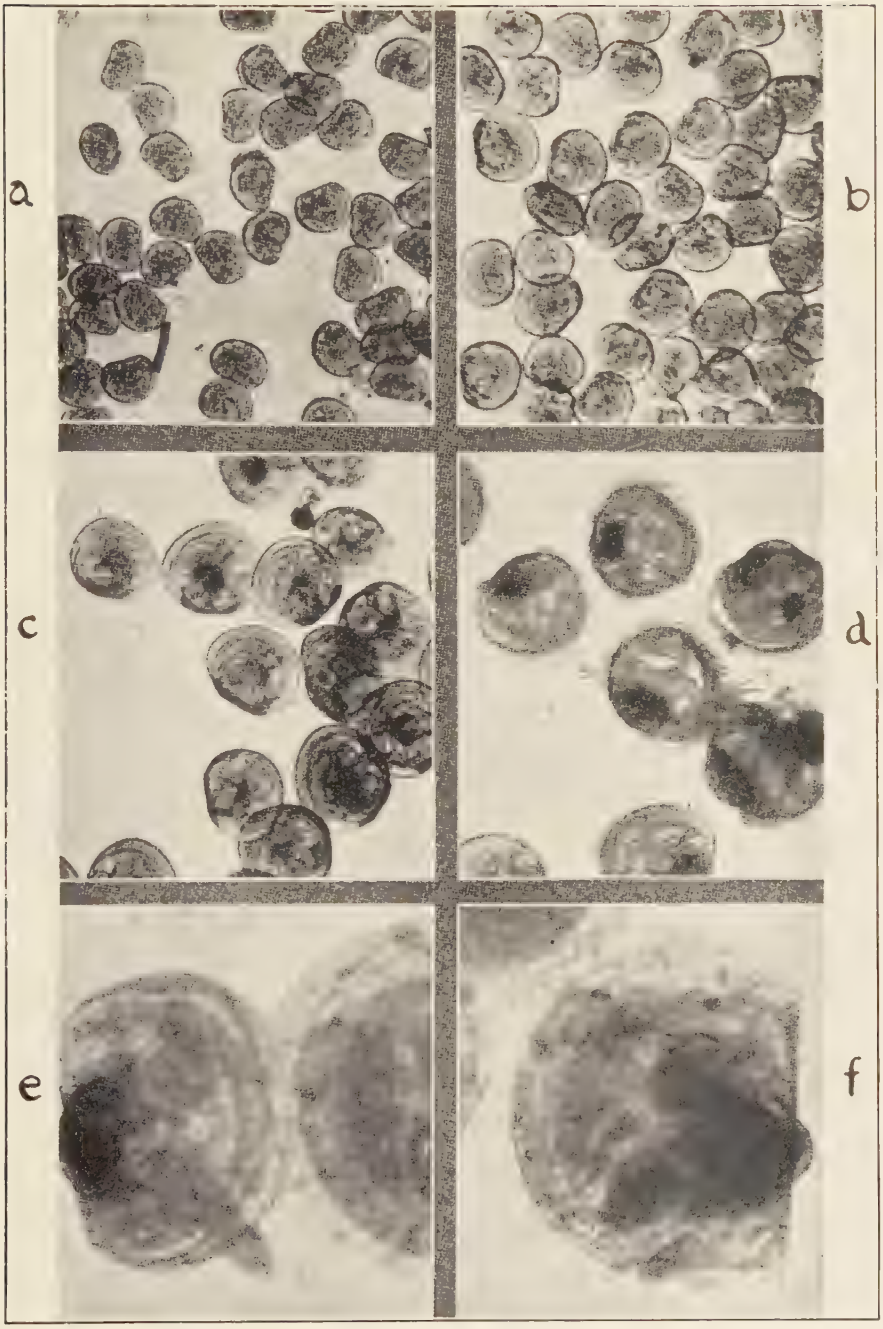

Figure 22.—Early scallop stages: *a*, early; *b*, intermediate; and *c*, late prodissoconchs. *d*, early; *e* and *f*, later nepionic stages. From Wells, 1927, by permission of the State of New York Conservation Department

POSTLARVAL DEVELOPMENT

It is usual to consider the late veliger or prodissoconch as ending the larval stage, and this is done here, although it is realized that the changes yet to be passed through are considerable.

The first postveliger stage is here termed the *nepionic* (after Jackson) rather than *dissoconch* [5] and begins with the appearance of the compressed, wide-spreading shell characteristic of this stage, not only in the scallop but also in the oyster. The new shell growth quickly assumes a shape resembling that of the adult, with long, straight hinge, byssal notch, and cycloid outline, but without ribs. (Figs. 21 and 22.) It begins with a length of about 0.18 millimeter and ends with one of about 1 millimeter (fig. 21), when the ribs begin to appear. During this period of growth gills attain 15 or 20 reflected filaments, heart and pericardium become plainly visible, the intestine comes to lie close to the adductor muscle which becomes large and differentiated into motor and catch portions. A few ocelli (6 in 1 specimen) and tentacles (15 in 1 specimen), together with the flap, appear around the mantle margin and palps near the mouth. The animal can attach by the byssus, crawl with the foot, swim much as in the adult, and float at the surface with the foot extended along the surface film. In the laboratory a specimen even floated for two hours at the film after the foot had been withdrawn into the shell. The foot is large, ciliated, and very active; the tentacles, papillose and sensitive. At or just after the end of the nepionic period (as indicated by shell development) the visceral mass and filaments of the outer demibranch begin to appear.

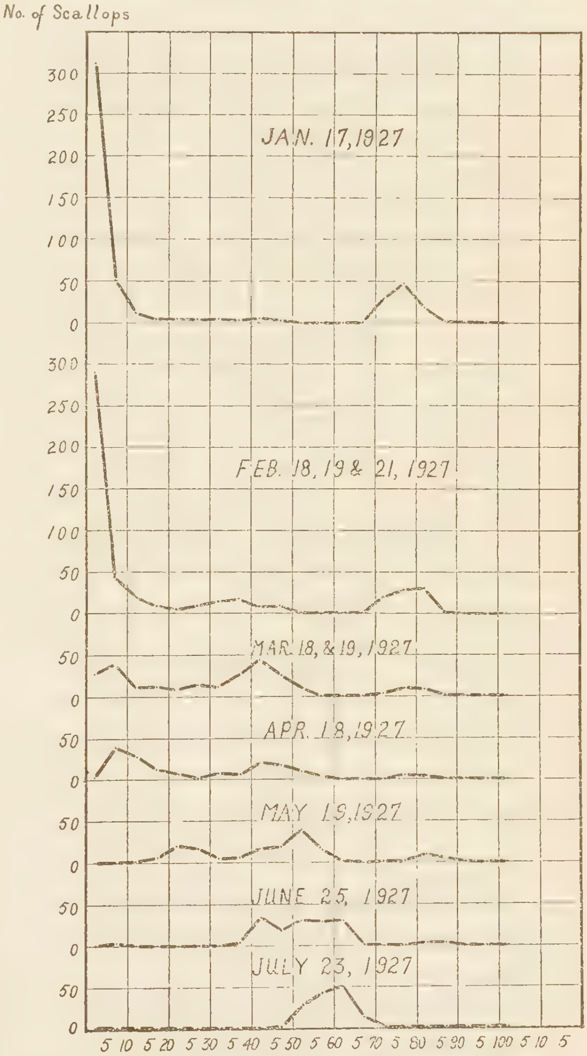

FIGURE 23.—Length-frequency curves based on one collection at Pivers Island, for each month of the first half of 1927 (5-millimeter groupings). (See Table 4)

A transition or plicate stage is recognized by Jackson. This (Fig. 21*m*) begins with the appearance of shell ribs and continues to a size of about 4 millimeters when an appearance strikingly like that of the adult is attained. During this period the "guard" tentacles appear, and lips, gills, mantle margin, visceral mass and structures, generally, attain rather closely to the condition of the adult.

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[5] Dissoconch is sometimes used specifically to designate this early stage. However, Jackson (1890, p. 281), who apparently originated the term, applies it to the shell of the adult and of all postveliger stages. See also Korschelt (1900).

GROWTH, AGE AT MATURITY, AND LENGTH OF LIFE (ANNUAL GROWTH LINE)

Although scallops from various areas have been collected and measured, the material from which was obtained the data chiefly used in the study of growth rate, age at sexual and commercial maturity, and length of life, was secured from the Pivers Island bed close to the laboratory. This was a desirable selection because of its ready accessibility and because during the first summer it offered the only known ample supply. An unfailing natural bed so close at hand has proved highly desirable, lacking only freedom from molestation by man[6] to be nearly perfect.

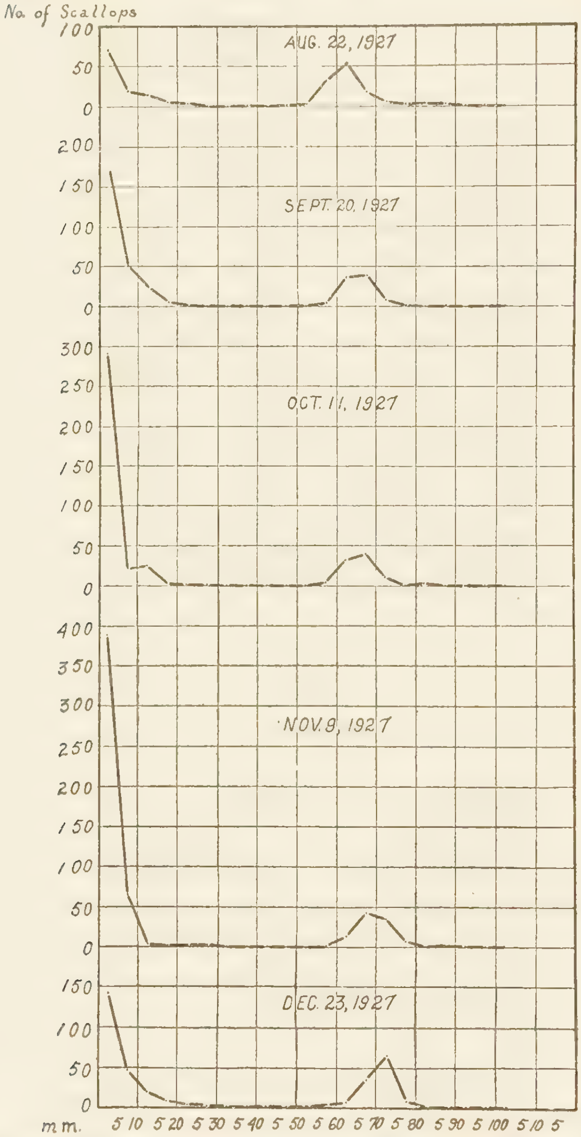

FIGURE 24.—Length-frequency curves based on one collection at Pivers Island, for each month of the second half of 1927 (5-millimeter groupings). (See Table 4)

Collections of scallops for measurement were made twice monthly over a large portion of the time. Of the scallops of considerable size, the attempt was made to secure a hundred. Therefore the number of these taken, unless markedly below that number, is not indicative of abundance. On the other hand, by the fall of 1926 collections for small scallops, which, as previously noted, not only dwell amidst vegetation but also attach themselves to it by means of the byssus, generally were made by raking a tubful of eelgrass. Numbers of these, therefore, are indicative of abundance. (See Tables 4 and 5.) One collection, as here considered, generally was made on 1 day, rarely on 2 or 3 days, and with an elapsed time of not over 4 days. In no instance is a size frequency curve a composite of two collections, as here defined.

The series of size-frequency curves (Figs. 23 and 24) show the year classes present and their appearance, growth, and disappearance. At the first of the year two classes are present in abundance, one composed of small individuals varying much as to size, the other of large scallops of a compact size group. As the season progresses the effect of growth becomes very evident in the first class and, in time, the effect of market scalloping in the second class. By the end of the scalloping season, except for a few stray old scallops, there is present only one class. This class, because of the extended and probably irregular spawning season, for a time is lacking in compactness and may even appear divided, but by June or July becomes compact and so continues until all but eliminated by scallopers. Through the few left it may be followed (1927) into the next fall. In 1927, the first year in which suitable methods for securing very small scallops were applied throughout the year, the new class appeared in the summer. This class became prominent in late summer and through the fall and early winter increased greatly. Figure 25 shows the size frequency distribution at different seasons in different years.

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[6] In the summer of 1926 a portion of these flats was set aside by the State to be excluded from commercial scalloping. Unfortunately, it has seemed impracticable to prevent serious molestation.

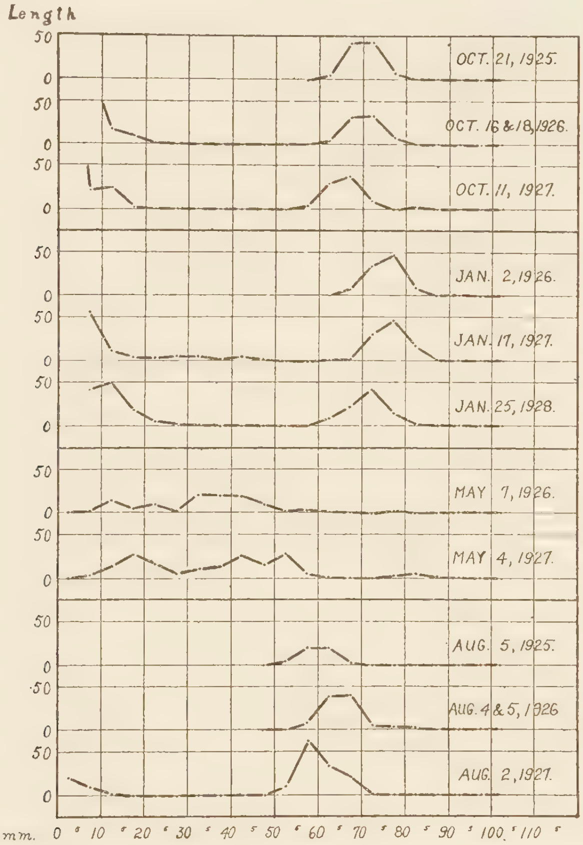

FIGURE 25.—Scallop length-frequency curves (5-millimeter groupings) for various years at various seasons. To save space and facilitate comparison, if large numbers of small scallops were found this part of the curve has been omitted. (See Table 5)

TABLE 4.—*Numbers of scallops of all sizes (in 5-millimeter groups) taken in the various collections through 1927 at Pivers Island. (See figs. 23 and 24)*

Length, millimeters	January	February		March		April		May		June		July		August		September		October	November	December
	17	1	19	5	20	4	18	4	19	3	25	8	23	2	22	6	20	11	9	23
0 to 4.5	313	256	290	40	27	13	4	----	----	4	1	4	3	22	71	243	174	290	387	142
5 to 9.5	56	36	46	21	39	53	41	4	----	----	4	----	1	10	19	63	51	22	56	47
10 to 14	13	19	18	6	13	21	28	14	2	----	1	----	1	3	14	12	26	26	4	19
15 to 19	5	19	8	2	12	18	13	27	7	----	----	----	----	----	6	3	6	3	2	8
20 to 24	4	7	6	5	9	2	8	17	20	2	----	----	----	----	4	3	2	1	3	4
25 to 29	6	7	8	10	14	5	2	6	17	13	----	----	----	----	----	1	----	1	2	1
30 to 34	6	33	14	27	12	8	7	12	5	23	----	----	----	----	----	----	----	----	----	1
35 to 39	3	19	17	49	27	7	7	14	7	22	5	1	----	----	1	----	----	----	----	----
40 to 44	6	17	8	31	44	21	22	26	17	23	34	3	----	1	----	----	----	----	----	----
45 to 49	3	7	10	20	26	15	17	16	20	21	19	25	3	----	1	1	----	----	----	----
50 to 54	----	2	2	6	10	7	10	29	39	35	32	46	29	12	1	2	----	----	----	----
55 to 59	----	----	----	----	1	1	4	6	16	42	30	36	43	65	32	4	5	4	1	2
60 to 64	1	1	----	1	----	----	----	2	3	6	32	19	50	35	52	45	37	32	13	7
65 to 69	2	6	2	----	1	----	----	----	----	----	3	5	12	22	18	34	39	40	43	35
70 to 74	32	22	18	12	5	1	----	----	1	1	----	2	3	3	5	8	8	11	35	65
75 to 79	44	44	29	41	10	5	6	4	2	3	1	1	1	----	2	2	1	----	7	8
80 to 84	18	26	31	31	9	5	4	6	10	3	2	3	----	1	2	----	----	2	----	----
85 to 89	3	4	4	9	1	1	1	2	5	3	1	3	2	2	1	2	1	----	1	----
90 to 94	1	1	1	----	----	----	----	----	1	----	----	1	1	----	----	----	----	----	----	----

TABLE 5.—*Data as to lengths of scallops from certain seasonal collections in 1925, 1926, and 1927. Pivers Island, 5-millimeter groupings. (See fig. 25)*

Length, millimeters	Oct. 21, 1925	Oct. 16–18, 1926	Oct. 11, 1927	Jan. 12, 1926	Jan. 17, 1927	Jan. 25, 1928	May 7, 1926	May 4, 1927	Aug. 5, 1925	Aug. 4–5, 1926	Aug. 2, 1927
0 to 4.5	----	6	290	----	313	252	----	----	----	----	22
5 to 9.5	----	94	22	----	56	47	1	4	----	----	10
10 to 14	----	17	26	----	13	51	16	14	----	----	3
15 to 19	----	11	3	----	5	19	4	27	----	----	----
20 to 24	----	3	1	----	4	6	9	17	----	----	----
25 to 29	----	----	1	----	6	2	2	6	----	----	----
30 to 34	----	----	----	----	6	1	21	12	----	----	----
35 to 39	----	----	----	----	3	----	21	14	----	----	----
40 to 44	----	----	----	----	6	----	19	26	----	----	1
45 to 49	----	----	----	----	3	----	10	16	----	----	----
50 to 54	----	----	----	----	----	----	2	29	5	1	12
55 to 59	----	----	4	----	----	----	4	6	21	10	65
60 to 64	5	6	32	----	1	8	1	2	20	41	35
65 to 69	43	32	40	8	2	23	----	----	3	40	22
70 to 74	43	34	11	36	32	42	----	----	----	6	3
75 to 79	8	8	----	47	44	15	2	4	----	4	----
80 to 84	1	1	2	9	18	12	----	6	----	4	1
85 to 89	----	----	----	----	3	----	----	2	----	----	2
90 to 94	----	----	----	----	1	----	----	----	----	----	----
95 to 99	----	----	----	----	----	----	----	----	----	----	----

From the data presented in these graphs it is evident that the life of a year class is as follows: It originates from summer to winter but principally in the fall, grows to sexual maturity so that its members spawn the next fall (summer to winter) when a year old. In its second winter it constitutes the market class and, as such, is nearly eliminated. Of the few not marketed some survive until the succeeding December, but neither these data nor some experiments in which scallops were confined in a pen give any close indication as to the portion which survive until then, or even to summer.

The length of life attained by the great majority of scallops reaching maturity is not over 20 months, but can not be stated with exactitude because of the extended spawning and marketing seasons. There is no evidence of any old age mortality before the close of the market season. Of those caught at the end of the season (last of April) a very few may be 21 months old, more of them 19 or 20, and a goodly proportion about 16 months. Ordinarily, comparatively few survive until the closing days of the season. By the last of February the supply is greatly reduced. At that time some of them are only about 14 months old, many not over 16 months, and the majority not over 18 months. Great numbers of scallops are caught in December when many are about 12 months old, and the majority not over 14 months. Under present conditions the length of life of the majority of scallops attaining to maturity may be taken to be from 12 to 18 months.

The normal length of life may or may not be a very different thing from the general length of life of mature scallops. Belding (1910) found that Massachusetts scallops (which spawn in June and July) suffered a heavy mortality in the spring following the market season and when lacking a few months of being 2 years old. Only a few survived to 2 years and a second spawning. This was the more remarkable because in all cases noted development of sexual products in preparation for a second spawning began and continued normally until death intervened. This suggests not death from old age but from some pathologic factor. A few survived to a second spawning and even to an age of 30 months.

Because destruction of adult scallops by man generally is so extreme in North Carolina, the problem of the normal length of life, or the length of life of scallops not destroyed by man, is difficult to determine. It is evident that some survive to 2 years of age, or somewhat more but not what portion would do so. It is not even clear that there is any general mortality following the market season and preceding a second spawning (to correspond with the spring mortality reported by Belding). With scallops of rapid growth, such as those at Pivers Island, growth becomes slower after the second winter and there is no reason to believe that the normal span of life is much over 2 years. Questions of practical importance are what proportion, if spared by man, would survive to a second spawning, and what proportion would survive to a second market season; that is, third winter. The evidence is scanty and inconclusive.

As judged by the prevalence at all times of various sized shells of recently dead scallops, there is considerable mortality at all times and ages. Because of this, any special mortality rate, among the few scallops ordinarily spared at the end of the market season, must be rapid and heavy to be definitely determined. There are no direct observations nor data to show such mortality. It is possible, however, that there is a gradual but high mortality through the second summer and the following autumn. Unless freshets or other natural agencies caused special destruction this could be determined if man did not interfere.

When the market season closed in the spring of 1929 there were still, as scallopers and dealers have stated, many adult scallops remaining in western Bogue Sound. This was because, on the one hand, these small scallops had been very abundant and, on the other, the market was poor. These small scallops bring the lowest return and in such a season are hardly desired by the dealers at any price. When I visited western Bogue Sound in November, 1929, I found among the usual small 1-year-old scallops (40–54 millimeters but principally 45–50 millimeters long) commercial quantities of scallops of large size (many of them 75 to 80 millimeters, some as small as 70 and one 65 millimeters long). These large scallops have an evident annual growth line (see succeeding paragraphs) at about 50 millimeters. There seems no reason to doubt that they were 2-year-old scallops.

Thus it is shown that in some situations scallops may survive to 2 years or more of age in considerable proportion and quantity. It is also shown that in so doing they may increase greatly in bulk and consequently in value. This leads to another question: Do the scallops of slow growth, and consequent small size at 1 year of age, live longer than those of rapid growth? In Massachusetts, Belding (1910) found this to be the case. If this is true also in North Carolina, the results found in western Bogue Sound are not indicative of what would occur in the more valuable areas which produce large scallops in one year. They do indicate, however, that failure to market the full annual crop in these areas is not all loss by any means. Indeed it is possible that it might be more profitable in such areas not to market the small yearling scallops, but to leave them to grow.

Beginning with late spring and early summer the growth of scallops which will make up the market class of the succeeding winter is well shown by the increase in average length. (Tables 6 and 7, and fig. 26*c*.) Until about this time there is extreme variation in size, and through the preceding fall and into the winter the continued addition of new stock has reduced the average so that average increase in size is considerably less than growth rate. The advance of the mode offers an even less satisfactory method of study, because of continued dominance of the very small scallops in my collections. Until late spring, growth rate of scallops less than 1 year old seems best represented by the increase in size of the largest of the year class. (Fig. 26, *b* and *d*.) These largest individuals apparently do not increase their lead over the others and may be taken to be older than more rapid-growing individuals. Typical sizes are shown by the size-frequency curves.

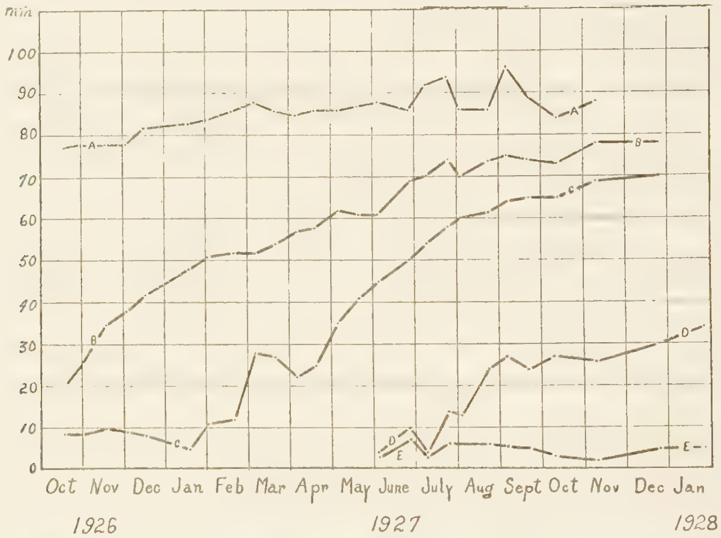

FIGURE 26.—Growth of scallops at Pivers Island, N. C. *A*, Longest of 1925 year class as determined by Table 8 (there is some uncertainty as to a few points, particularly the highest which may represent an older class); *B*, longest of 1926 year class (see Tables 7 and 8); *C*, average length of 1926 year class (see Table 6); *D*, longest of 1927 year class (Tables 7 and 8); *E*, average length of 1927 year class (see Table 6)

The sizes given in these growth and size frequency curves apply strictly only to the scallops of the Pivers Island flats. In a general way they apply to the scallops of other beds in Beaufort Harbor and in eastern Bogue Sound, some of which produce larger scallops and other smaller ones. The scallops of Core Sound and particularly of western Bogue Sound in general are much smaller.

TABLE 6.—*Average lengths (millimeters) of scallops of certain year classes according to collections made at Pivers Island. (See fig. 26)*

Date	1926 year class	Date	1926 year class	Date	1927 year class
1926		1927		1927	
Oct. 17	9	May 19	41	May 19	
Oct. 30	9	June 3	45	June 3	3
Nov. 17	10	June 25	52	June 25	7
Dec. 1	9	July 8	54	July 8	3
Dec. 15	8	July 23	59	July 23	6
1927		Aug. 2	60	Aug. 2	5
Jan. 17	5	Aug. 22	61	Aug. 22	6
Feb. 1	11	Sept. 6	64	Sept. 6	6
Feb. 19	12	Sept. 20	65	Sept. 20	5
Mar. 5	28	Oct. 11	65	Oct. 11	3
Mar. 20	27	Nov. 9	69	Nov. 9	2
Apr. 4	21	Dec. 23	70	Dec. 23	5
Apr. 18	25	1928		1928	
May 4	36	Jan. 25		Jan. 25	

TABLE 7.—*Length frequencies of scallops collected at Pivers Island, October 17, 1926, to January 25, 1928. (See fig. 26)*

Length millimeters	1926					1927																				1928
	October		November	December		January	February		March		April		May		June		July		August		September		October	November	December	January
	17	30	17	1	15	17	1	19	5	20	4	18	4	19	3	25	8	23	2	22	6	20	11	9	23	25
Under 2				12	18	119	96	13								1	1		5	24	173	20	172	244	[1]33	176
2				21	42	45	44	79	2	2					1			1	3	19	31	17	55	45	[1]33	40
2.5 to 3.5	4	7	5	45	71	122	90	138	24	12	1	2			1		2	2	5	22	21	78	53	67	30	18
4 to 4.5	2	21	13	23	31	27	26	60	14	13	12	2			2		1		9	6	18	59	10	31	46	18
5 to 5.5	9	13	12	24	25	20	11	16	7	13	9	7				1			2	5	8	12	7	30	14	7
6 to 6.5	21	12	10	22	22	11	6	14	7	9	17	8							3	4	23	20	3	16	18	18
7 to 7.5	25	5	7	13	12	10	6	6	2	7	11	6	1						1	4	10	6	5	4	3	7
8 to 8.5	26	16	5	9	21	8	7	5	3	8	13	8	1			1			3	5	19	7	4	6	10	8
9 to 9.5	13	13	6	14	9	7	6	5	2	2	3	12	2			2		1	1	1	3	6	3		2	7
10	11	15	1	13	16	2	4	1	1	7	5	7	1			1				4	1	6	7	1	7	14
11	3	6	3	11	5	5	4	2	1	1	3	5	1						1	4	1	2	9	1	2	10
12	2	4	5	6	21	3	5	4	1	1	5	6	4							5	5	8	3	1	6	10
13		5	4	6	7		2	4	2	2	4	3	3						2	1	3	3	2		3	8
14	1	6	4	10	3	3	4	7	1	2	4	7	5	2				1			2	7	5	1	1	9
15	2	3	5	3	8		3	2		1	5	4	8								1	4	1		2	5
16	4	2	3	8	12	1	3			3	3	3	7							3	1		1	1		8
17	4		2	2	5	2	2	1		3	3	1	2	1								2	1	1	2	2
18	2	1	1	8	1	2	7	5	1	4	6	3	5	2						1					2	3
19	1		2	3	3		4		1	1	1	2	5	4						2	1				2	1
20	3	2	1	2	1	1	2	2		3		2	2	3						1		1	1	2		4
21			2	1	1	3	2		1	2		1	1	2							1					1
22		1		5	5		1	3	1		1	3	7	7						2	1				3	
23		1		2	4		1		2	2		2	2	4											1	
24				4	5		1	1	1	2	1		5	4	2					1	1	1		1		1
25		1			4	3		1		2	1			2	1									1		1
26				3	3	2	3	4			1		1	4	2									1		
27		1	1				2	1	2	4		1	3	3	3						1		1			1
28				1		1		1	4	5	2	1	2	4	2										1	
29			1		2		2	1	4	3	1			4	5											
30				1	1		5	2	4		2	1	4	2	6										1	
31				1		1	3	3	3	2	2		1		3											
32				2		1	9	2	5	3	1	1	2	1	4											
33						2	1	1	7	3	1	3	2	2	5											1
34			1	1		2	15	6	8	4	2	2	3		5											
35							4	3	2	2	1	1		1	6											
36					2	1	4	1	12	6	1	2	1	2	6	1										
37				1	1		7	1	11	7	2		5	1	4	1										
38				1	2	1	3	5	15	6	2	2	3	3	1	1										
39					2	1	1	7	9	6	1	2	5		5	2	1			1						
40					1	1	3	2	8	10	7	4	1	2	3	3	1									
41					1	1	1		5	8	1	2	8		5	6										
42					1	2	4	2	7	11	6	5	6		4	9										
43							5	2	5	6	4	4	4	3	7	8										
44						2	4	2	6	9	3	7	7	12	4	8	2		1							
45						1	3	3	4	4	3	5	1	2	3	5					1					
46						1	2	2	3	2	3	5	2	6	5	6	5									
47							1	1	5	4	4	3	4	2	4	2	7	2								
48				1		1		2	6	6	3	3	6	6	5	3	9	1		1						
49							1	2	2	10	2	1	3	4	4	3	4									
50							1	1	1	2	1	4	7	8	9	8	7	6	2							

[1] These data recorded as 2 millimeters or under (66) arbitrarily divided as into equal portions.

TABLE 7.—*Length frequencies of scallops collected at Pivers Island, October 17, 1926, to January 25, 1928*—Continued

Length millimeters	1926					1927																				1928
	October		November	December		January	February		March		April		May		June		July		August		September		October	November	December	January
	17	30	17	1	15	17	1	19	5	20	4	18	4	19	3	25	8	23	2	22	6	20	11	9	23	25
51							1		1	2	2	2	5	7	4	5	18	4								
52				1				1	4	1	1	3	8	10	10	6	9	5	3							
53										2		1	5	5	4	2	6	6	2	1	1					
54					1					3	3		4	9	8	11	6	8	5		1					
55													2	5	8	4	9	10	9	4						
56												1	1	6	12	7	7	9	17	3		1	2			
57											1	1	1	4	8	7	8	7	8	8	1	2			1	
58												1	2		8	9	7	9	18	6	2		2		1	
59										1		1		1	6	3	5	8	13	11	1	2		1		
60		1		1	1				1				1	2	2	10	6	12	4	11	8	5	4	2		1
61	1	1	1	1										1	4	8	4	5	8	6	8	4	5	3	1	
62		1	1	2	1								1			6	1	15	7	14	11	10	8	1	1	
63	3	3	1		1	1	1									5	4	12	10	15	4	11	6	3	3	2
64	2	7	2	2	1											3	4	6	6	5	14	7	9	4	2	5
65	8	9	2	4	1		2									2		2	10	5	11	7	7	6	5	2
66	6	4	7	3						1							2	4	7	2	12	14	11	10	6	3
67	3	2	7	3	3												2	2	5	3	7	8	10	8	4	6
68	10	15	11	8	3	1	3	2										2		3	1	5	10	13	7	8
69	5	12	8	6	5	1	1									1	1	2		5	3	5	2	6	13	4
70	6	9	11	13	14	3	2	1	2								2	1	3	3	3	5	3	13	14	9
71	8	6	11	8	7	6	1	2	1	1				1							1	1	3	5	13	11
72	6	8	4	11	8	9	5	2	2	1								1		1	2		3	6	16	11
73	8	7	9	8	12	4	3	4	5	1											1	1	2	5	12	8
74	6	1	10	5	13	10	11	9	2	2	1				1			1		1	1	1		6	9	3
75	2	6	1	8	4	9	8	6	7		1		1								1			1	5	5
76	3	1	6	5	8	13	16	2	6	3	1	1	2		1		1	1						2	1	4
77	3	1	1		7	10	8	6	10	3	1	1			1					1				3	1	4
78		1	3	11	2	7	8	10	12	4		2	1	2	1	1					1			1	2	2
79		1	1		2	5	4	5	6		2	2								1		1				
80					4	7	9	8	9	5	1	1	2	4	1	1			1	1						2
81			2			2	8	8	12	1		1		1		1										
82	1				4	4	5	7	5	2		1	2	1			1									
83						4	2	5	2		3	1		1	1		2						1			
84		1		1		1	2	3	3	1	1		2	3	1					1			1			
85		1					1	3	3		1			3	1		2					1				
86						3	2	1	5	1		1	2	1	1	1	1	2	2	1						
87				1			1							1							1					
88									1						1									1		
89																					1					
90		1			1																					
91							1																			
92						1								1			1									
93								1																		
94																		1								

Usually in the fall, rarely in the summer or as late as early winter, there is formed the only growth line which is present consistently. On the average and perhaps nearly always it represents an age of very close to 1 year and reasonably may be termed a 1-year line or annual-growth line. Its cause is not easy of determination.

This first-year line has been found, although rarely, as early as September. One old scallop was found in July with what appeared to be a second annual-growth line or 2-year line. Because the line presumably is formed by interruption of growth and because growth is continued through the winter (see fig. 27) it is evident that the growth cessation is not due to too low a temperature.

Seasonal plankton change is another conceivable explanation. Although against it may be brought not all the arguments against temperature, at present there is no direct, positive evidence in its favor and no sufficient basis for its acceptance.

In regard to spawning or spawn production the case is less indefinite. The line typically is a fall line; spawning occurs principally in the fall. Rarely a newly formed line is found in summer or early winter; the spawning season begins in the summer and extends to early winter. In individual cases, however, no close correlation between the amount of new growth—that is, growth outside the line—and the state of

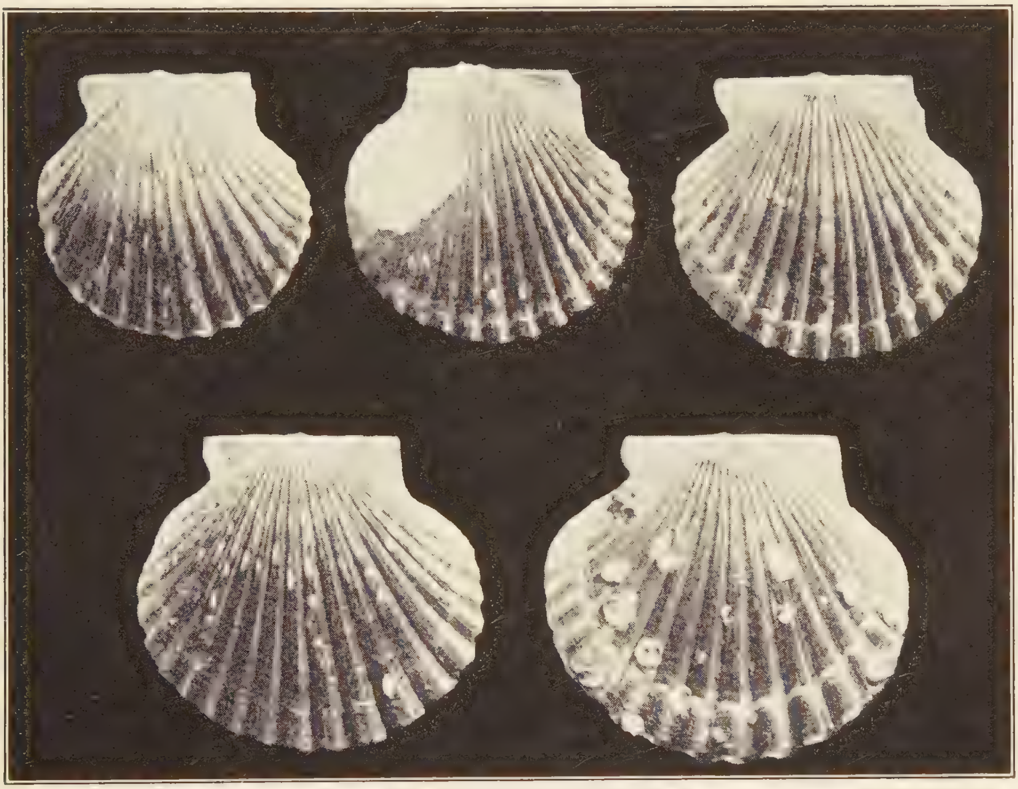

FIGURE 27.—Series of scallops with growth line illustrating the fact that this line is formed in the fall, when scallops are spawning and are about 1 year old. The scallop at the upper left-hand corner, with line just formed, was taken October 30; the second one, December 1; the third, January 31; that in the lower left corner, February 20; and that in the lower right corner, July 23. (1926 and 1927, Pivers Island, N. C.) One-half natural size

the gonads has been found consistently. A scallop might have much new growth and gonads far from empty or little new growth and gonads nearly emptied. Although such cases are extreme, it seems clear that the significant factor is not spawn emission. If growth cessation is causally connected with the spawning season (and such a hypothesis is deemed worthy of tentative acceptance) it would seem that some metabolic activity, indirectly connected with the development of eggs and sperms, must be responsible.

In this connection it is interesting to note that Risser (1901) working in Rhode Island and Belding (1910) working in Massachusetts, arrived at opposite conclusions as to the factor producing the annual-growth line. Risser found the spawning season to correspond well with the month of June and the growth line to be formed by an interruption of growth during that month. His growth curve, although it leaves such a possibility, does not show complete growth cessation during June. Neither does it definitely show growth cessation during the winter, but it indicates that if growth had ceased it was resumed by mid March. His photographs of scallop shells show no growth line by May 31 (too late, it would seem, for a winter line) but a noticeable resumed growth on shells taken July 1 to 12 and, therefore, indicate that the growth line was formed in June, the spawning month.

Belding (loc. cit.) states that the growth line is due to growth interruption not in the spawning season but rather in the winter months. In support of this assertion he gives various growth curves showing complete cessation of growth from December 1 to May 1, with a sharply marked resumption of growth on May 1. Instead of cessation of growth during the spawning season (June–July) he found a reduced growth rate (also shown in graphs). His excellent photographs of scallop shells with and without growth lines, bear no dates and, therefore, furnish no evidence pro or con. His graphs, with the sharp rise through May, the reduced inclination through June and July, and the increased inclination through August, September, and October, plainly indicate winter (and spring) cessation rather than spawning season cessation as productive of the growth line. However, it is to be considered that the time between growth resumption and spawning is short (about a month) and that not the act of spawning but rather metabolism connected with egg and sperm development may be the factor causing growth cessation. The fact that growth is shown through a period does not preclude the possibility that there has been a cessation at some interval or intervals during that period; that is, that a second growth interruption may have occurred. Moreover Belding's growth curves consist of a series of connected straight monthly lines connecting single points for each month. No collection dates nor data as to the numbers measured are given, and there is nothing to show that measurements were made at closer intervals as would be necessary to preclude the possibility of growth cessation going unrecorded.

To a degree my investigations tend to corroborate the findings of Risser and to oppose those of Belding as to the factor affecting the annual-growth line. Furthermore certain possibilities for error in Belding's conclusions are suggested (see preceding paragraph). It is, however, altogether reasonable that in northern areas the severe cold would stop growth and that the vernal resumption of growth, especially with a rapidly growing animal, would leave a well-marked growth line. Even if growth ceased for a time during the spawning season, the effect of this might be merged with the recently formed winter line.

Hopkins (1930) quotes Belding as to age and growth of Massachusetts scallops and the present writer as to Beaufort scallops.

The annual growth or first-year line has been assumed, in this discussion as elsewhere, to mark an interruption in growth. Indeed, indication of autumnal growth interruption among adults has been found. However, and especially in the upper valve, the line in question is not marked by a noticeable ridge or "terrace" but by color difference. In the lower valve the growth outside the line is unpigmented and, until discolored by growths and stains, pearly white, and is much more noticeable in this valve than in the upper. In time, however, the older part of this white growth often becomes so discolored as to make difficult the determination of the line. No such difficulty is encountered with the upper valve. In it the white (or light) growth is not long continued (ordinarily for a width of about 1 millimeter) and is followed by the usual darkly marked shell material. Obscured by extraneous growths and dirt and even darkened somewhat by stains, with a cleaned shell it stands out plainly against the dark of the upper valve and, except very rarely, is unmistakable.

ENVIRONMENTAL FACTORS

BOTTOM

Of the vast array of factors affecting a salt-water animal and constituting its environment, only temperature, salinity, current, depth, and bottom are directly considered here. The term "bottom" is used to include not only the soil but also its vegetation. As previously noted, the bay scallop is almost confined to grassy (chiefly Zostera) areas. Just why this is the case seems not to have been explained. The writer suggests that it is because early postveliger stages generally find satisfactory conditions for survival only where the vegetation affords suitable conditions for attachment above the substratum, and because subsequent migration is so slight as to leave nearly all scallops in grassy areas.

Grassy bottom, therefore, may be taken to be generally necessary for the bay scallop's existence in certain early stages of development. What its influence is on the subsequent life of the scallop, the writer is not prepared to state. Belding (1910) believed that much vegetation retarded growth. Although some of the best growing areas are very grassy, it is possible that growth in these areas would be better if the vegetation were less dense. However, it seems that locally the density of the vegetation is not very important in the growth of the scallop. This is a point of importance if scallop culture were to be developed. Possibly nongrassy areas would give better growth and prove more satisfactory for planting than grassy ones. On the other hand, scallops, which normally shift little, might dislike bare bottom and scatter badly. The type of soil influences the appearance but, within suitable limits, has little other direct effect.

DEPTH OF WATER

The depth of water is important to scallops in so far as it protects them from the effects of severe cold or from their enemies. The herring gull catches scallops only on flats exposed or nearly exposed at low water. The depth affords some protection from man in two quite opposite ways. In areas where raking is the only legal method of taking scallops, the depth of water over scallops sometimes is sufficient to be of protection from rakers. In other areas, where scallops are small and of such little value that raking them seldom is considered profitable, there is sometimes so little depth of water that even the small dredge boats can not navigate. This, of course, serves to protect the scallops from man. Sometimes in severely cold weather, as that which occurred late in December, 1925, there is considerable mortality among scallops in very shallow water or on flats which are exposed or nearly exposed at low water. Depths in productive areas are seldom over 6 feet and generally less than that. In a large proportion of the areas it is not over 3 feet. Scallops of the most rapid growth and largest size are found both on flats in shallow water and in the greater depth of channels. In some areas larger scallops are found in channels, but this may be chiefly a matter of current rather than depth.

CURRENT

Water currents are important in various ways. Undoubtedly they effect distribution of scallops, as of other oviparous bivalves, by carrying eggs, embryos, and larvæ, but to what extent and in just what way is not well understood. In addition, by carrying the loosened vegetation from scallop beds, currents doubtless transport scallops considerable distances, and may sometimes establish them in distant areas. Currents also bring food and O_2 to the scallop and so become very important.

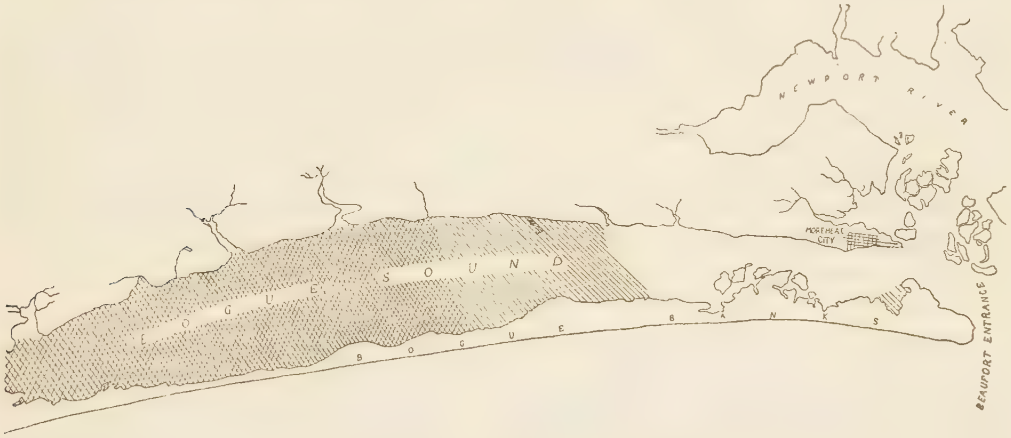

FIGURE 28.—Bogue Sound, showing areas of strong tide and rapid growth (unshaded); moderate tide and slower growth (single shaded); and little tide and poor growth (double shaded)

Because both salinity and scallop size generally decrease away from the inlets at first it seemed that salinity was the principal factor affecting the scallop growth rate. Later, as scallops became reestablished over considerable and varied areas, it became evident that the areas of rapid growth were not so much areas of saltier water as areas of greater current.

This is illustrated in Core Sound, where larger scallops are found along the west shore near the southerly end where the main current enters and leaves; in Beaufort Harbor, where scallops of moderate size are found on Town Marsh flats nearest the inlet but so situated that the tide rises over and flows off but does not traverse them; but is most easily illustrated in Bogue Sound.

Figure 28 shows Bogue Sound, from Beaufort Inlet (which furnishes much the greater tidal flow to and from the sound) nearly to the western end. It is divided into three sections. In the eastern section near the inlet, growth is rapid and produces the largest and most highly prized scallops in North Carolina. In only one productive area are the scallops of relatively inferior size (60 to 70 millimeters). This is in Tar Landing Bay, nearest the inlet but so protected by land that the tide merely rises and falls, does not sweep through. In the other productive areas the tide is very strong.

In the adjoining intermediate section the tide is reduced but still periodic. Growth is less rapid so that year-old scallops are of moderate size (60 to 70 millimeters).

The third section is that termed western Bogue Sound in this paper. Tidal flow generally is slow or, over the great expanses of scallop shoals, wanting or almost wanting and the water level greatly affected by winds. The main channel is a dredged one along the north shore. Scallop-producing areas constitute a large, perhaps the larger, portion of this section and yield great numbers of scallops. Growth is slow and the year-old scallops small but varying considerably in size over this large area (40 to 60 millimeters). Two-year-old scallops attain a much larger size.

The sound salinities normally are high, generally over 30 parts per mille and rarely as low as 27 parts per mille. Summer salinities in western Bogue Sound run as high as 37 parts per mille.

Although no quantitative data are available to show the relation between current and growth rate, it seems to me that the case is a fairly obvious one and that there is no reasonable ground for doubt that current is the chief physical factor governing growth in Bogue Sound. In other sections the case is not quite so simple and obvious but higher growth rate still is attributable to stronger current. Presumably this is in part because the current brings food, but the fact that it brings an abundance of O_2 and carries away products of vegetable decay besides CO_2, and so prevents injurious results from stagnation, may be more important. It should be considered that in the sluggish, slow-growing areas, the severity of warm-weather conditions may be a principal retarding factor.

SALINITY

Although salinity is an essential condition of the environment of the bay scallop, the limits are not easily determined. Only the lower limit is of presumable practical importance, because bay scallops are to be found in the most saline waters of their range (total salinity about 38 parts per mille). The minimum salinity may well be considered under two heads, which I term the "freshet" or temporary minimum and the distributional or continued minimum.

The distributional minimum is taken to be the lowest salinity to be found within scallop areas except during extreme freshets. This minimum has been sought particularly in Core Sound, which ordinarily contains scallops only in its southerly saltier portion but which in the winters of 1926–27 and 1927–28 contained them also in its northern portion near where it joins the less saline Pamlico Sound. The lowest salinity found in scallop areas in Core Sound or elsewhere, except during severe freshets, was 20 parts per mille, with 21.3 parts per mille or higher almost universal. (See Giral, 1926, as to the accuracy of salinity determinations.) This figure of 20 parts per mille therefore is taken as the distributional minimum.

Even in the saltier portions of the scallop-producing areas severe freshets occur which are extremely destructive. In September, 1924, a freshet occurred which almost completely destroyed the scallops (unless perhaps the very young) in all areas except those off Morehead City in lower Bogue Sound. The salinities prevailing off Morehead City during this freshet are not known, but those at Pivers Island became as low as 6 parts per mille (Table 8 and fig. 29). Because of the tidal conditions appreciably higher salinities might well have prevailed, and doubtless did prevail off Morehead City. In 1921 freshets reduced the salinities in the Harkers Island section, which includes southern Core Sound, to 13–16.6 parts per mille[7] on February 7. Scallops are reported to have been then in very poor condition. In March scallops were not being taken there commercially, but whether because they had all been caught or because of mortality in situ is not known. Tables 8 and 9 and Figures 30 and 31, show noticeably reduced salinities at Pivers Island early in 1924 and 1925. Because scallops were generally abundant in the summer of 1924 and at Pivers Island in 1925, it is evident that this low salinity caused no extreme mortality, at least among the young. In February and March, 1926, salinities as low as 20 parts per mille were attained. In January, following the severe cold of late December, there was noticeable mortality among adult scallops, but not in February or March. In October, 1928, as a result of unusual inland rains in September, observed salinity at Pivers Island became as low as about 19 parts per mille (18.6 parts per mille as calculated from routine hydrometer readings). This freshening was accompanied or followed by a considerable mortality among adult scallops at Pivers Island and other places in Beaufort Harbor. In Newport River the destruction was so great as to cause the general abandonment of its scallop grounds in the ensuing commercial season. Just how fresh the water over these grounds became is not known. However, near the mouth of the canalized connection with Neuse River and within the extreme limits of scallop extension, a salinity of 4.8 parts per mille was found. In Core Sound scallops survived salinities at least as low as 16.2 parts per mille (at Marshallberg) although in poor condition and perhaps with considerable delayed mortality.

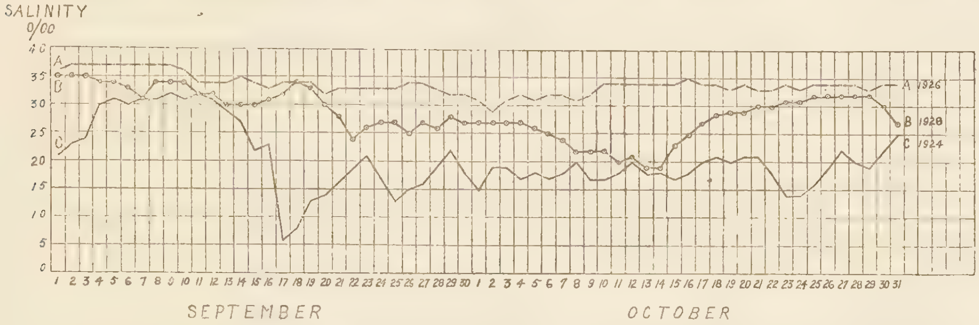

FIGURE 29.—Daily salinities at Pivers Island through autumnal periods of extreme scallop destruction (1924), moderate mortality of adults (1928), and good survival (1926). (Based on one hydrometer reading daily, corrected for temperature but instrumental error not known.) See Table 9

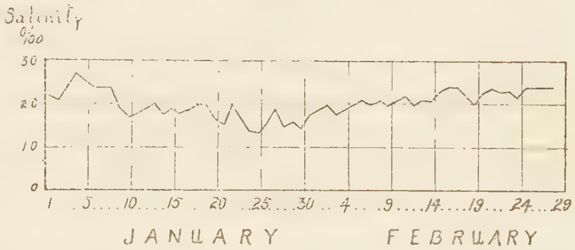

FIGURE 30.—Daily salinities through a winter period (1925) with low salinities which produced no noticeable mortality and certainly spared sufficient young scallops for a good crop the succeeding winter (based on one hydrometer reading daily corrected for temperature but instrumental error not known)

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[7] These figures for total salinity are based on data expressed as NaCl kindly furnished with other information by Dr. J. J. McManus, chief, Savannah station; Food, Drug, and Insecticide Administration; United States Department of Agriculture. The analytical work in this instance was done by James O. Clarke of the Food, Drug, and Insecticide Administration.

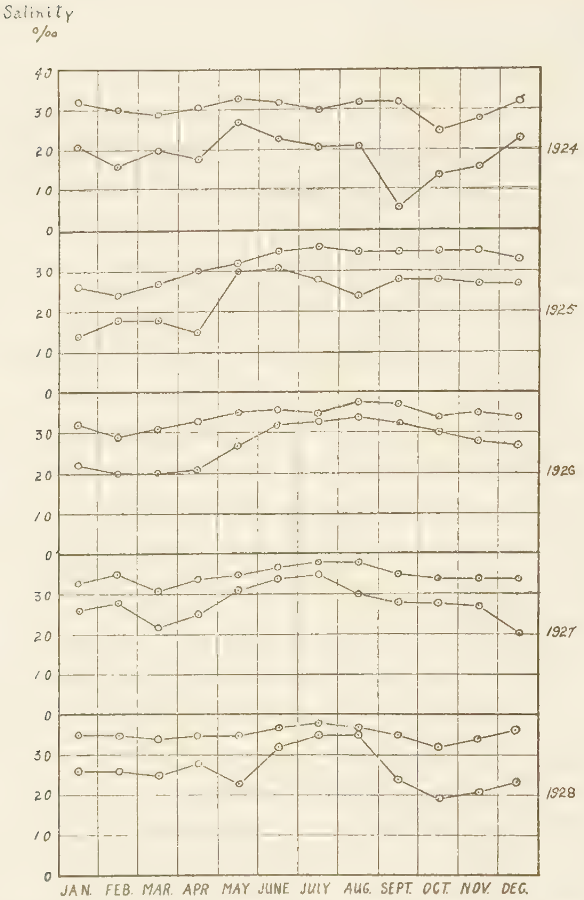

FIGURE 31.—Monthly maximum and minimum salinities at Pivers Island, 1924–1928. (Based on one daily hydrometer reading, corrected for temperature but instrumental error not known.) (See Table 10)

TABLE 8.—*Daily salinities at Pivers Island through autumnal periods of extreme destruction, moderate mortality, and good survival*

[Fractions of parts per thousand are omitted]

AUTUMN SALINITIES

Date	Day of month																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
September, 1924	21	23	24	30	31	30	31	31	32	31	32	31	29	27	22	23	6	8	13	14	---	---	21	17	12	15	16	19	22	8	---
September, 1926	36	37	37	37	37	37	37	37	37	36	34	34	34	35	34	33	34	34	34	32	33	33	33	33	33	34	34	33	32	32	---
September, 1928	35	35	35	34	34	33	31	34	34	34	32	32	30	30	30	31	32	34	33	30	28	24	26	27	27	25	27	26	28	27	---
October, 1924	15	19	19	17	18	17	18	20	17	17	18	20	18	18	17	18	20	21	20	21	21	18	14	14	16	19	22	20	19	22	25
October, 1926	31	29	31	32	31	32	32	31	32	34	34	34	34	34	34	35	34	34	33	34	33	33	34	33	34	34	34	34	33	34	34
October, 1928	27	27	27	27	26	25	24	22	22	22	20	21	19	19	23	25	27	28	29	29	30	30	31	31	32	32	32	32	32	30	27

WINTER SALINITIES

January, 1925	22	21	24	27	26	24	24	24	19	17	18	19	20	18	19	18	19	20	20	17	16	20	17	14	14	16	19	15	16	15	18
February, 1925	---	20	18	19	20	21	20	21	20	21	22	20	21	21	23	24	24	24	20	23	24	23	23	22	24	24	24	24	---	---	---

TABLE 9.—*Extreme monthly maximum and minimum salinities at Pivers Island, 1924–1928*

[Fractions of parts per thousand are omitted]

Year	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
MAXIMUM												
1924	32	30	29	31	33	32	30	32	32	25	28	32
1925	27	24	27	30	32	35	36	35	35	35	35	33
1926	32	29	31	33	35	36	35	38	37	34	35	34
1927	33	35	31	34	35	37	38	38	35	34	34	34
1928	35	35	34	35	35	37	38	38	35	32	34	37
MINIMUM												
1924	21	16	20	18	27	23	21	21	6	14	16	23
1925	14	18	18	15	30	31	28	24	28	28	27	27
1926	22	20	20	21	27	22	33	34	32	30	28	27
1927	26	28	22	25	31	34	35	30	28	28	27	20
1928	26	26	25	27	23	32	35	35	24	19	21	23

When fall towings were begun at Pivers Island in 1928, larvæ believed to be those of the scallop were taken regularly. They soon disappeared, however. This might have been one of the vagaries of distribution or collecting but, in view of the failure of the "set" or crop of young it seems probable that it was due to death from the freshets which were responsible for a destruction vastly more serious than that of adults.

At Pivers Island, routine daily hydrometer readings are taken. Although these might readily miss the extreme reduction during a brief freshet, they would be expected to yield satisfactory data for a long-continued saline reduction such as occurred in the fall of 1928. However, although there was definite mortality, presumably due to the freshet, not only at Pivers Island but also nearer the inlet, the lowest reading corresponds to a salinity of about 19 parts per mille. (Fig. 30.) If the figures obtained really represent the lowest salinity occurring over the Beaufort Harbor scallop beds, it is indicated that salinity reductions below 20 parts per mille are dangerous. On the other hand the fact that the salinity in Newport River at a point where salinities of 25 to 35 parts per mille were found before the freshet, went as low as 4.8 parts per mille would make it appear not improbable that salinities at its mouth (that is, in Beaufort Harbor) went considerably below such a figure as 19 parts per mille.

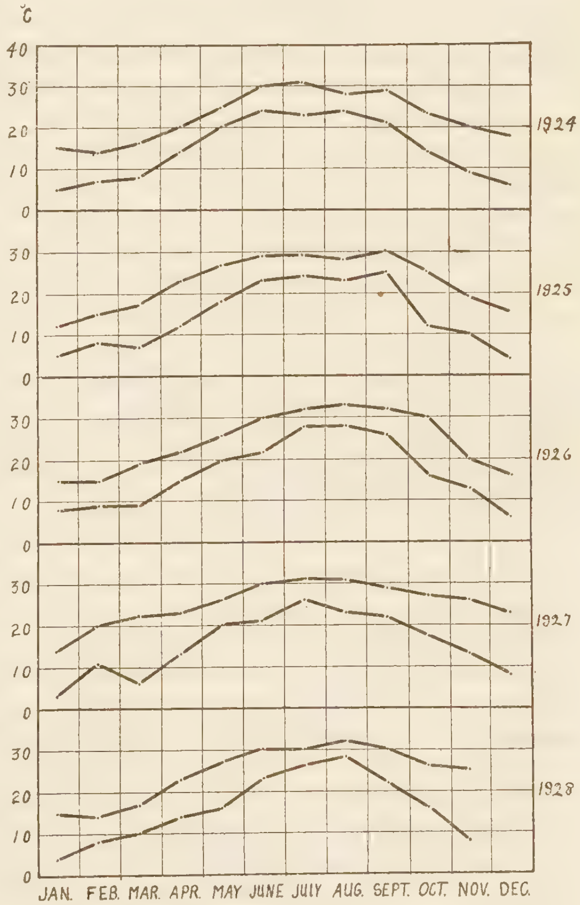

FIGURE 32.—Monthly maximum and minimum water temperatures at Pivers Island, 1924–1928, based on one reading daily. (See Table 12)

From the foregoing evidence it is difficult to determine the lowest salinity which the bay scallop will temporarily survive. A salinity as low as 6 parts per mille evidently is destructive. In various instances salinity reductions to 13–14 parts per mille have not proved quickly fatal to adults and there is evidence of ample survival by young during a period of salinity reduction which on two succeeding days was as low as 14 parts per mille. (See table 8 and fig. 31). In contrast we find in 1928 scallops at Pivers Island dying in appreciable numbers and apparently because of a freshet which was not found to go below 18.6 parts per mille. In the case of adults, at least, the delay between undue freshening (unless it is extreme, as in 1924) and death seems to be extraordinary (weeks or even months). Death from freshets may occur considerably after an improvement in salinity.

One of the possibilities suggested by the inconsistent results of water freshening is that not NaCl reduction but some change in minor constituents is the major factor in the destructiveness of freshets.

With a more hardy form, definite experimental information as to permissible salinities would have been sought. The great uncertainity of scallop survival in aquaria was taken to indicate as unwise efforts in this direction.

Although a distributional as distinguished from a temporary minimum salinity is here considered, it is possible that the prevailing or so-called distributional minimum is merely incidental, and that the only functional minimum—where considerable fluctuations occur—is the temporary, and that it depends on the length of time involved and even on the prevailing salinity.

The evidence was at first taken to point to a correlation between growth and salinity. Later investigations, however, pointed to current as the principal factor, and no clear relationship between salinity and growth was found.

A temporary reduction in salinity "fattens" or "swells" scallops by lowering the osmotic pressure of the surrounding medium so that the tissues of the scallop absorb water and become distended. Thus in Core Sound, where the tidal effect of wind is pronounced, a cold snap with its northerly wind and consequent influx of less salty water from Pamlico Sound, results in plump scallops and has led to the belief that sudden cold fattens scallops.

TEMPERATURE

Upon the feeding and growth of various lamellibranchs, water temperature has been found to exert a profound direct effect. At a temperature approaching 0° C., the activity of gill cilia nearly ceases so that syphoning (and consequently feeding) becomes negligible. Up to a limiting temperature (in certain instances in the neighborhood of 30° C.) the ciliary activity and rate of syphoning increases with the temperature. Thus Round (1914), studying the rate of bacterial elimination in oysters, found that above 9° C. there was evidence of pronounced gill currents, but that at 5° C. only after five days was there reduction; Nelson (1921) found that from 0° to 5° C. the feeding current of the oyster was extremely minute; Gray (1923) states that the ciliary speed (*Mytilus edulis*) increases from 0° to 33° C.; and Galtsoff (1926) found that the optimum (for the oyster) lies between 25° and 30° C. with no current produced at or below 5° C.

Examination of the temperature graph (fig. 32) and Table 10 shows that water temperature at Pivers Island varies from a minimum of 3° to 6° C. generally in January, to a maximum of 30° to 33° C. in July, August, or September. This, and the generally even character of the maximum and minimum curves, would suggest a cycle of growth beginning with zero or nearly that (and a growth line) in January and culminating in mid or late summer. However, it is to be noted that January temperatures fluctuate from a minimum of 3° to 5° C. to a maximum of 12° to 15° C. so that there is opportunity for growth at this season even if feeding does not occur at or below 5° C. or some temperature close to this. A further complicating factor is the early maturing, with short life. Thus growth rate for one year is complicated by all the physiological changes involved in the transformation from minute larva or early postlarva to large mature adult. The "annual" (about 1 year old) growth line generally is formed in the fall when it could be explained as directly due to temperature only on the assumption that the sudden autumnal temperature drop, or the loss of summer warmth, temporarily inhibits growth.

Table 10.—*Monthly maximum and minimum water temperatures (° C.) at Pivers Island, 1924–1928, based on one reading daily*

Year	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
MAXIMUM												
1924	15	14	16	20	25	30	31	28	29	23	20	18
1925	12	15	17	23	27	29	29	28	30	25	19	15
1926	15	15	19	22	26	30	32	33	32	30	20	16
1927	14	20	22	23	26	30	31	31	29	27	26	23
1928	15	14	17	23	27	30	30	32	30	36	25	18
MINIMUM												
1924	5	7	8	14	20	24	23	24	21	14	9	6
1925	5	8	7	12	18	23	24	23	25	12	10	4
1926	8	9	9	15	20	22	28	28	26	16	13	6
1927	3	11	6	13	20	21	26	23	22	17	13	8
1928	4	8	10	14	16	23	26	28	22	16	8	5

A noticeable direct effect of temperature comes with extreme cold. Thus late in December, 1928, unusually cold weather was accompanied by extreme ebb tides that left the scallop flats exposed (but not quite free of water which, as usual, was impounded by vegetation, etc.) for considerable intervals. As previously stated, it is believed that the considerable scallop mortality which followed was due to unusual chilling. Extreme water temperatures on the flats under such conditions doubtless exceed those recorded, as do also those under similar tidal but reverse temperature conditions in summer. Thus in the instance cited, with an air temperature (at night) of about −10° C., it is not impossible that the little water left on the flats at low water became colder than 0° C. Some few scallops may have been directly exposed to the air temperature. The recorded minimum water temperature (4° C.) is extreme for December.

ENEMIES AND PARASITES

Of the animals which prey upon postlarval scallops, the best known are the starfish, the oyster drill, and the herring gull. Of these the herring gull is much the most conspicuous. From fall to spring at Pivers Island the gulls are daily to be seen, as the tide drops, floating over the scallop flats and—when the flats become sufficiently exposed—catching the scallops, dropping them on the beach to crack the shells, and eating them. This happens also at other beds about Beaufort and Morehead City where the scallops are especially valuable. Obviously many marketable scallops are thus destroyed. However, it is to be considered that the greater portion of the scallop-producing areas are not sufficiently exposed by the tide to enable herring gulls, which are poor divers, to get the scallops. Furthermore these gulls, notable scavengers, are abundant principally about harbors.

Ducks, and possibly other water birds, occasionally feed extensively on young scallops. In the winter of 1921–22 the white-winged scoter was found to be decidedly destructive to scallops in Massachusetts (Nelson, 1922).

The oyster drill, listed by Belding (1910) as a principal enemy of the scallop, does not seem to be destructive here, for almost no drilled scallop shells have been noticed. It is thought that ordinarily the drill, which moves slowly, is not an important enemy of the scallop,which is active and quick moving.

The starfish is considered by Uexküll (1912) to be the principal enemy. Possibly it is, except for man, the principal predatory enemy of adult and juvenile scallops. Locally, starfish occasionally are found eating scallops. Of the recently emptied scallop shells generally to be found on scallop beds, it is impossible to say what portion are the work of the starfish, for, unlike the drill, it leaves no identifying mark. It has not been found in great abundance on North Carolina scallop grounds. In some regions the starfish may be extremely destructive. In North Carolina it probably is considerably destructive but not a menace. The experiments of Dakin (1910) and Uexküll (1912) indicate that the scallop particularly avoids starfish.

Possibly predatory planktonic forms and larger animals which feed upon plankton are much more destructive of scallops (larvæ) than any forms which prey upon juveniles or adults.

As previously noted, examination of tables and graphs of scallop collections, shows tremendous reduction in abundance of scallops above the smallest sizes. (See Tables 4 and 7 and figs. 23. and 24.) During times of abundance the largest collections of scallops under 5 millimeters is about eight times as great as that of any group over 5 millimeters at any time of the year. Moreover the smaller sizes are much more apt to escape notice than larger ones. Thus an average mortality of perhaps 85 per cent between some size under 5 millimeters and one between 5 and 10 millimeters is indicated. More specifically, from Table 9, it appears that mortality is most severe from 3.5 to 10 millimeters. There is no evidence as to whether or not this is due to predatory animals.

Comparatively few scallop parasites seem to be known. Dakin (1909) found *Lichomolgus maximus*, an ectoparasitic copepod, on the gills and mantle of *Pecten maximus*, but no internal parasites in that species or in *P. opercularis*. At Beaufort I have found trematodes and a nematode.

According to the investigation of Dr. N. A. Cobb (1930) only one nematode (a larva) previously has been found in a scallop (Vadel, 1855). The one (*Paranisakis pectinis* Cobb, 1930) I found in the visceral mass thus appears to be the second ever found in a scallop.

It has been reported (private correspondence) that trematodes are not found in *P. irradians* at Woods Hole. At Beaufort I have found them on the gills, in the gills, and in the walls of the stomach.

On a few occasions I have found scallops the gills of which bore large numbers of trematode sporocysts. When these were examined fresh, each sporocyst was found to contain several rediæ and each redia hundreds of cercariæ which were released when a cover glass was placed over a redia (so that the cercariæ were released prematurely and may have differed considerably from mature cercariæ). Some few cercariæ were surrounded by a membrane, presumably the original covering of the germ ball.

In the spring of 1928 I found a scallop of the market class of the preceding winter with a parasite present in the interlamellar septa of the gills and abundant in the wall of the stomach. Thereafter, every scallop of this class examined was found with this parasite in the walls of the stomach, generally in abundance. In the winter of 1928–29 it was again found prevalent. The appearance suggested a recently encysted miracidium, or a very young sporocyst. Later examination of Tennent's (1906) account and illustrations (see his fig. 12) of *Bucephalus haimeanus*, and reexamination of material, led me, as Tennent had been led, to doubt this. The particular stage in the life of the parasite, which is assumed to be a Gasterostome, therefore, is not clear. Neither is its effect upon the scallop. With the oyster and some other lamellibranchs, Gasterostome infections render the host sterile, but there was no indication that the scallop was so affected by this parasite. In addition Tennent found evidence indicating that heavy infection rendered the oyster unable to resist unfavorable conditions. It is possible that the puzzling mortality which followed the apparently moderate freshening of the water over certain areas in the fall of 1928 was due in part to lowered resistance from these parasites.

Parasitic infection is worthy of consideration in connection with certain aspects of the life history of the scallop. The length of life of the scallop is unusually short. Moreover (as previously noted) Belding, working in Massachusetts, found that, although scallops generally died in the spring before they were 2 years old, gonadal development began as for a second spawning and continued to this end if the individual survived to the spawning season. This would suggest that some specific disease caused the mortality, and not old age. The intensity and the apparent universality of the parasitic infection just described seemed a reasonable explanation. However, examination of scallops from Massachusetts stated to be 22 months old did not reveal the parasite. The decided natural mortality reported by Belding has not been observed by me (although it might be evident were it not for the extreme destruction wrought by man) either in the time of year or at the age when he found it.

As a higher vertebrate which feeds on the adult scallop in areas where parasitism is prevalent, the herring gull is suggested as a probable host of later stages of parasites of the scallop.

Besides these definitely parasitic forms, a supposedly commensal crab, *Pinnotheres maculatus* Say, is to be found frequently in scallops in North Carolina. Although Hay and Shore (1918) state that only the female is common, three of four specimens sent to the National Museum and identified by Dr. Mary J. Rathbun proved to be males. As to the actual relationship between mollusk and crab the writer has no evidence to offer.

IMPORTANCE OF A KNOWLEDGE OF SCALLOP BIOLOGY FOR CONSERVATION

Scallop conservation at present is almost entirely[8] a matter of legal regulation. In order that regulation may be intelligently applied or the possibilities understood of supplementing it by more active means, such as scallop farming, a considerable knowledge of scallop biology is essential. Points of special importance for conservational regulation are: Time of spawning, age at sexual maturity, age at marketing, and length of life. Thus the knowledge that in North Carolina the bay scallop spawns in the fall, is sexually mature in a year, and suitable for marketing the succeeding winter, when a little over a year old, greatly simplifies the problem of regulation. It makes a winter market season ideal, for at that time the only scallops large enough to be profitably marketable are mature and have spawned. With spring spawning many, if not most, of the immature scallops would be large enough to market and might make up the bulk of the catch. The problem of conservational regulation with a winter market season would then be different and much more difficult. Extreme destruction by man of mature scallops makes it difficult to determine the normal length of life. However, the knowledge that nearly all the scallops are immature in the summer makes it plain that scalloping at this time is wrong in principal and dangerous if carried on to an important extent or during a critical year.

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[8] Planting small scallops on private beds seems to have been practiced on a small scale at Wareham, Mass., for some time and may become an important industry on Cape Cod. At Wareham the town also pays for the transplanting of seed scallops from flats to deep water to prevent winter killing. At Nantucket transplanting has been tried experimentally.

For scallop farming it is important to know that scallops ordinarily shift little, increase rapidly in bulk, and are ready to market when a little over a year old. It is also important to know that they die quickly out of the water and that transplanting, therefore, would be much more apt to kill them than it would oysters or clams.

For a more detailed consideration of scallop conservation and of industrial scallop problems, generally, see Gutsell (1928).

SUMMARY

The bay scallop is of considerable economic importance. In value ($874,306 per annum according to statistics quoted) it ranks third among the edible bivalves of the Nation, after the oyster and the hard clam Venus. It is an article of commerce intermittently from Massachusetts to North Carolina where these studies were made and where it is of great local importance. Recently a small commercial catch in Florida has been reported.

Because of the types of interfilamentary connections to be found in certain European scallops, in the American bay scallop (*Pecten irradians*), and in the sea scallop (*Pecten grandis*) with vascular connections, it is considered that if classification into large groups is to be based on gill structure the scallops belong at the end of the group of bivalve mollusks the gills of which typically are without vascular connections (Filibranchia) and adjacent to (and connecting with) the group typified by interfilamentary vascular connections (Eulamellibranchia). This agrees with the arrangement of Ridewood (1903) but not with his terminology.

As stated by various writers, the range of the bay scallop is from Massachusetts to Florida or the Gulf of Mexico. It occurs principally in inclosed grassy waters of a depth varying from about a foot at ordinary low water to as much as 60 feet (Belding). In North Carolina it occurs principally in water less than 6 feet deep and of a normal salinity range of 38 parts per mille to 20 parts per mille.

Structure and function are considered at some length and in considerable detail. Studies were principally of living and fresh material.

Evidence from the examination of gonads and from periodic collections for young points to a spawning season beginning in mid or late summer, attaining its height in the fall, and continuing into January.

The form believed to be the late veliger or prodissoconch is equivalve, whereas Belding described and figured the late prodissoconch as inequivalve.

Sexual maturity and a large size are attained typically in the fall at an age of 1 year. In the vast majority of cases death comes at the hand of man before the next spring. So extreme is this destruction that the normal length of life has not been determined. A few individuals live to be about 2 years old and to spawn a second season, but what portion normally would do so, or the extreme age attained, is not known. Slow-growing scallops that are small when 1 year old may be large when 2 years old.

A prominent line, reasonably termed a 1-year line or annual-growth line is formed in the fall and followed by notable winter growth. It is tentatively assumed to be due to some metabolic activity connected with egg and sperm development. On the upper valve it is a light line on a dark ground.

Scallops seldom are found far from grassy bottom. It is here suggested that this is because eelgrass and associated vegetation comprise the most favorable objects of attachment for the young and because thereafter scallops usually shift but little.

Depth is not found to be very important except as shallow water exposes the scallops to the attacks of enemies and the effect of unusual cold.

No close correlation is found between growth and salinity. Scallops taken in water of a winter salinity of 20 parts per mille to 21.6 parts per mille were larger than those from some areas where much higher salinities prevail. Although scallops have been found, in poor condition but alive, in water of a salinity as low as 13 parts per mille and although there is evidence of plentiful survival at least by the young of reductions nearly to this figure, considerable mortality presumably attributable to low salinity in certain instances has followed reductions to about this concentration. The delay between water freshening and scallop death may be great. A reduction to 6 parts per mille at Pivers Island was almost if not quite completely destructive, at least of adults. Moderate mortality in Beaufort Harbor followed a reduction in the fall of 1928 not known to have gone below 18.5 parts per mille. The lowest concentration observed over scallop beds except in time of extreme freshets was 20 parts per mille, the highest observed 38 parts per mille.

From field observations it is concluded that among the physical factors affecting scallop growth, current is most important; the faster the current the more rapid the growth and the larger the market scallops.

Perhaps because of the rapid growth and early maturity and the absence of any prolonged period of water temperature sufficiently low to inhibit feeding no direct correlation between temperature and growth is found. The only consistent growth line appears typically in the fall, occasionally in the summer, and always by early winter. It can be accounted for on a temperature basis only on the supposition that temperature drop or loss of summer warmth temporarily causes growth cessation. This does not seem probable.

Enemies possibly are most destructive during larval and prelarval stages, but there is indication of very heavy mortality of scallops less than 10 millimeters long. Of the forms which prey upon adults and juvenile the best known are the starfish, the oyster drill, and the herring gull. Of these the herring gull is much the most conspicuous. In the limited but valuable areas subject to exposure at ordinary ebb tides it is considerably destructive. No evidence was found of serious destruction of scallops by oyster drills, and it is believed that the slow-moving drill ordinarily is not an important scallop enemy. The starfish, a destructive form, is not found to be a menace in North Carolina.

An account of two parasites, believed to be trematodes and apparently not previously found in scallops, is given. One of these, rarely found, occurred on the gills as a sporocyst, containing rediæ which contained very numerous, peculiar cercariæ. The other, found abundantly in the walls of the stomach, resembled the figure of a parasite found by Tennent in oysters at Beaufort and believed by him to be a stage of *Bucephalus haimeanus*. Largely because of this resemblance, the scallop parasite is considered a Gasterostome. The herring gull is suggested as a probable higher host species.

For conservation, which is by legal regulation of the fishery, it is important to know that the spawning season, beginning in the summer, and largely autumnal, extends into early winter, and that sexual maturity and marketable size are attained in a year. A closed season should begin in the spring before the young become marketable and extend to early winter. If restrictive measures are to be supplemented by active measures, as in some form of scallop culture, it is important to know that scallops ordinarily shift little and that certain areas produce larger and more valuable scallops, and that, therefore, such areas if depleted might well be stocked from areas which produce inferior scallops. The quickness with which scallops die out of water offers special difficulties to the planter. On the other hand rapid growth, early maturity, and high value offer special inducement.

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THE AGE AND GROWTH OF THE PACIFIC COCKLE (*CARDIUM CORBIS*, MARTYN)[1]

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INTRODUCTION

Cardium corbis, commonly known as the "cockle," is the most abundant and important species of *Cardium* found on the Pacific coast. It is widely distributed along the Pacific coast from southern California to the Pribilof Islands, Alaska, and as far south as Japan on the Asiatic shore. (Dall, 1916.) In the north it is found on tide flats in the bays, where it may be seen lying on top of the sand or barely beneath the surface. In the south it is found both in the bays and on the exposed beaches of coarse sand. The optimum locality for the species would appear to be in the Strait of Georgia, southern British Columbia, where they occur in great numbers. (Thompson, 1912; Weymouth, 1920.)

Although the cockle is very abundant in many localities and is an excellent food mollusk, it has never attained commercial importance because of its poor keeping qualities and small edible content. The local markets absorb small quantities, and many are used by the crab fishermen for bait. Attempts have been made to can the cockle, but have not met with notable success.

The data upon which this paper is based were incidentally collected by Dr. F. W. Weymouth, H. C. McMillin, and H. B. Holmes during the studies of the Pacific razor clam. Although the amount of material was relatively small, the homogeneity of the samples and the uniformity of clam growth have made it excellent material for growth studies.

AGE DETERMINATION

A quantitative analysis of growth data requires the knowledge of two variables—time and size. The absence of direct observation has required the use of the "annual rings" as measures of the time variable or age. The method is that which has long

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been used to determine the age of trees that in their structure show evidence of seasonal growth. Observers have established the presence of annual marks on the scales and otoliths of fish. Weymouth (1923) has shown in the Pismo clam and Weymouth, McMillin, and Holmes (1925) in the Pacific razor clam that there is a very definite relation existing between seasonal growth and the structure and external appearance of the shell. Rings are formed only once each year at the time of slow or suspended growth in the winter. Evidence of this cyclic growth in the Pismo clam has been presented by Weymouth (1923), and a retardation of growth during the winter months has been shown to occur in the razor clam by McMillin (1923), in the limpet (*Patella vulgata*) by Orton (1928), and in *Tellina tenuis* by Stephen (1929). By marking and holding Atlantic cockles (*Cardium edule*), Orton (1927) affirmed the validity of the rings as measures of age.

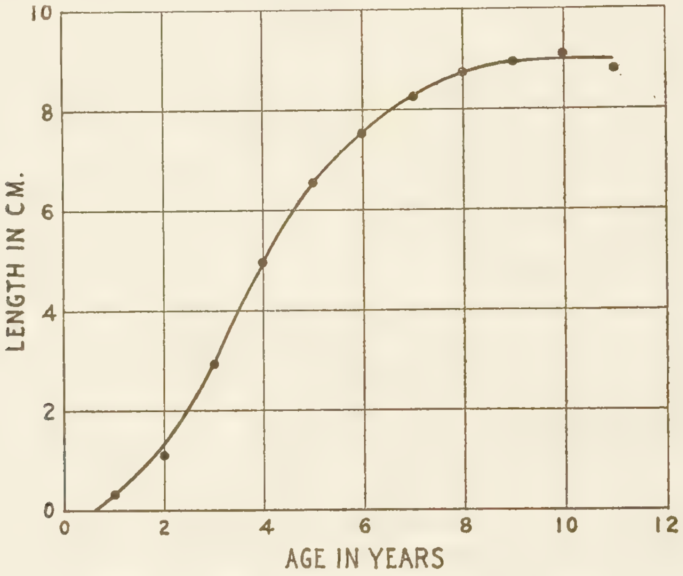

FIGURE 2.—Course of growth of *Cardium corbis* at Snug Harbor

GROWTH

In determining the size at the different ages the shells were measured radially from the umbo along the longest rib by means of calipers reading to tenths of millimeters. This rib, in *Cardium corbis*, is located near the posterior end of the shell. The annual rings to which the measurements were made are very definite and readily noted in the cockles from northern waters. The determination of the annual rings is more difficult on those from southern beaches, where winter growth is less retarded.

From measurements made in this manner the secular trend of the growth has been determined. The growth may be graphically represented by two methods, direct and logarithmic, and each type of curve has its particular value in the presentation of data. Figure 2 is an example of the direct presentation of growth and the curve is of the type most commonly used. This type of curve is constructed from the median length at each age, and is convenient for comparing the growth of closely related forms. (Brody, 1927.)

The life of this clam is sufficiently long to permit satisfactory trends of growth to be determined and to eliminate the effect of chance succession of favorable or un-

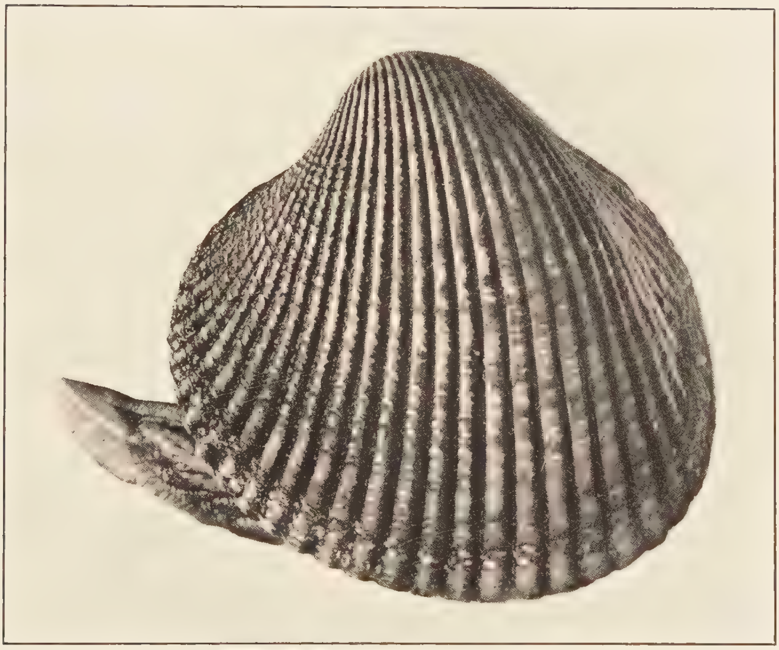

Figure 1.—*Cardium corbis*, Martyn

favorable years. The unusual uniformity of the data, due to the high correlation of the growth from year to year in the same individual, has resulted in very smooth growth curves. Figure 3 shows the uniform course of growth of two large individuals taken at Kukak Bay and at Port Moller, respectively.

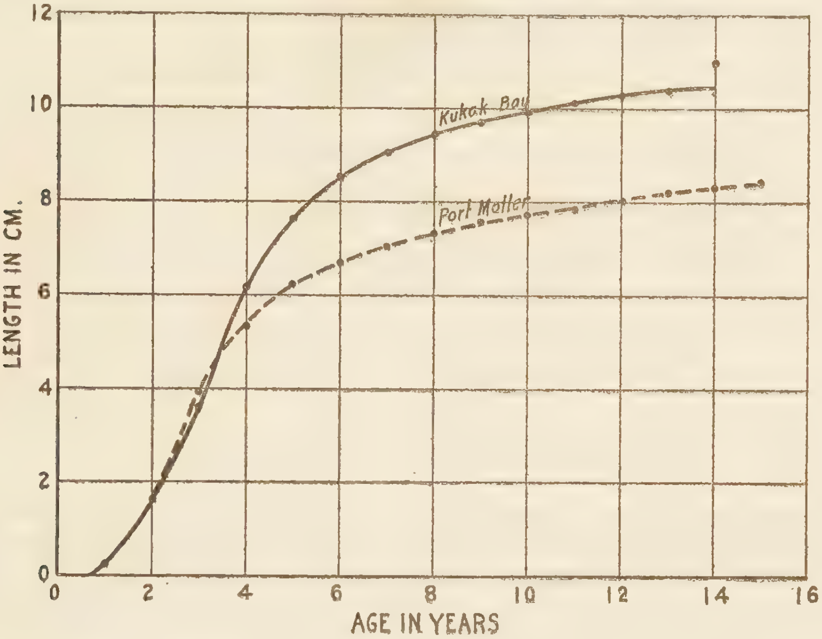

FIGURE 3.—Individual growth of *Cardium corbis* at Kukak Bay and at Port Moller

The same data may be further analyzed, and the differential of the first curve or the absolute annual increments may be plotted as in Figure 4 V. This curve shows

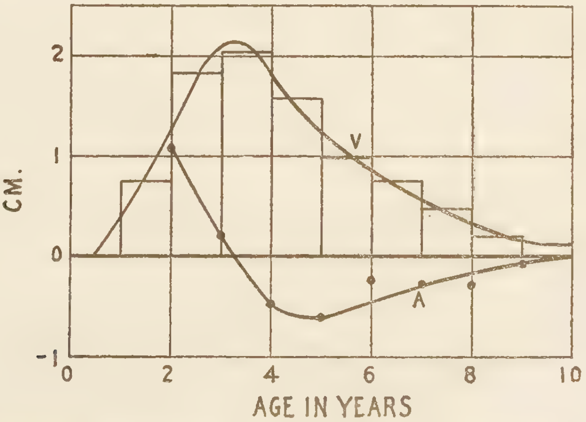

FIGURE 4.—The velocity (V) and (A) of the absolute growth of *Cardium corbis* at Snug Harbor

the velocity or time rate of growth and is useful to make conspicuous relatively slight variations in the curve, such as the presence of growth cycles.

The differential of this velocity curve—that is, the second differential of the original growth curve—represents the acceleration of the growth. Most growth data are so irregular as to make it impossible to use this curve, but the clam data are sufficiently uniform to give fairly smooth acceleration curves, as seen in Figure 4 A.

Since one can not readily see from the velocity curve the relative changes with time—the gain per unit of size—it becomes necessary to plot the ratio diagram of growth as in Figure 5. Minot (1908) emphasized the importance of relative growth. He says: "It is evident that the increase in weight depends upon two factors—first, upon the amount of body substance, or, in other words, of growing material present at a given time; second, upon the rapidity with which that amount increases itself." The "intensity" of growth can be shown only by the relative method. To do this the logarithms of the lengths have been plotted on the age. As a result, equal vertical distances represent equal relative changes, and equal slopes mean equal relative rates.

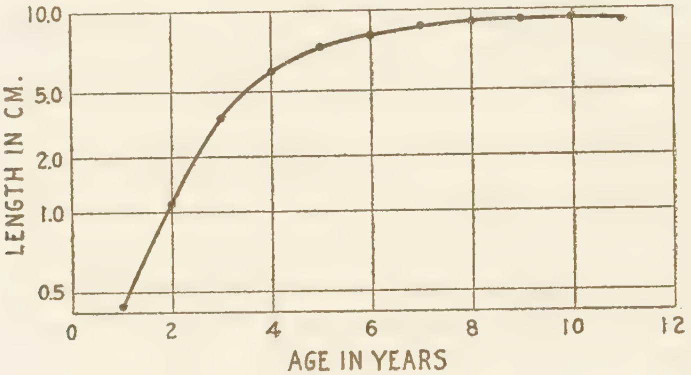

FIGURE 5.—Ratio diagram of the growth of *Cardium corbis* at Snug Harbor

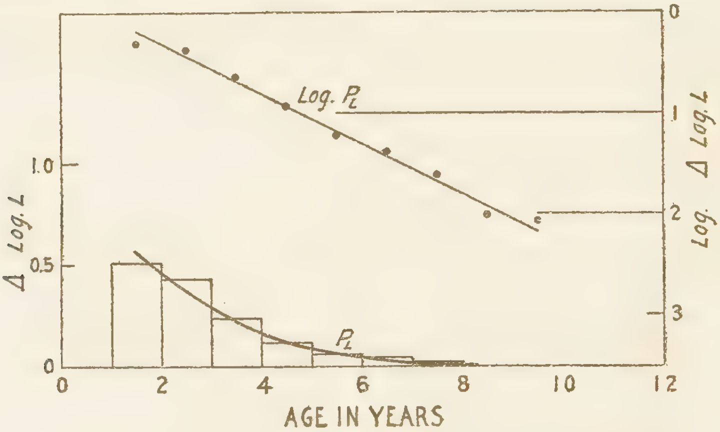

FIGURE 6.—Relative growth rate (P_L) $\left(\frac{\Delta \log L}{\Delta t}\right.$ from Figure 5) and logarithms of relative growth (log P_L) of *Cardium corbis* at Snug Harbor

Early growth is emphasized and late growth is minimized as a natural result of the relative aspect.

The differentials of the logarithmic lengths may be derived and plotted just as in the case of the absolute lengths. The first differential, in Figure 6, shows the declining relative growth rate so much emphasized by Minot. The decline of relative growth is an orderly process and may be fitted mathematically to some function of time. As shown by Weymouth, McMillin, and Rich (1931) and by Weymouth and McMillin (1931), this decline closely approximates an exponential series, so that the log of the relative growth rates plotted on age gives a straight line.

If relative growth rate $=\frac{d \log L}{dt}=P_L$, then

$$\log P_L = a - kt$$
$$P_L = e^{a-kt}$$
$$P_L = Ae^{-kt}$$

where $A=e^a$

$$\frac{d \log L}{dt} = Ae^{-kt}$$

$$\log L = \frac{-A}{K} e^{-kt} +$$

$$\log L = b - ce^{-kt}$$

where $c=\frac{A}{K}$

$$L = e^{b-ce^{-kt}}$$
$$L = Be^{-ce^{-kt}}$$

where $B=e^b$

Table 1 is a comparison of the observed lengths of *Cardium corbis* with the lengths calculated by the formula $L=Be^{-ce^{-kt}}$, developed by Weymouth, McMillin, and Rich (1930), and Weymouth and McMillin (1930).

TABLE 1.—*Comparison of observed and calculated lengths of Cardium corbis*

SNUG HARBOR

Year	N	L_o	L_c	L_o-L_c	P.E.$_o$	Year	N	L_o	L_c	L_o-L_c	P.E.$_o$
1	1	0.34	0.363	−0.023	----------	6	6	7.52	7.599	−0.079	0.2135
2	7	1.09	1.280	−.190	0.5018	7	6	8.27	8.289	−.019	.2164
3	7	2.92	3.040	−.120	.2394	8	6	8.75	8.705	.045	.4340
4	6	4.96	4.949	.011	.5281	9	3	8.95	8.949	.001	----------
5	6	6.54	6.511	.029	.2972	10	2	9.09	9.089	.001	----------

NOTE.—N=number of individuals; L_o=observed lengths; P.E.$_o$=probable error of observed lengths; and L_c=calculated lengths: $L=Be^{-ce^{-kt}}$, $L=9.27228e^{-6.247345e^{-.57442t}}$.

GROWTH IN DIFFERENT LOCALITIES

The three curves presented in Figure 7 show the marked variation in the growth of the species in different localities. These have been constructed from measurements of clams taken on the beds of Copalis, Wash., and Kake and Kukak Bay, Alaska. In general, it may be said that *Cardium corbis*, in the southern part of its range, makes a tremendous early growth, with which is associated a short life and a small size. The northern forms show a low initial growth rate, a long life, and a larger size than that attained by the southern forms. Insufficient growth data for the more southern forms have made it impossible to plot the course of their growth. However, where data have been obtained the growth resembles that of the Copalis cockle.

The growth of *Cardium corbis* is an interesting confirmation of the conclusions reached by Weymouth, McMillin, and Rich (1930) in regard to the growth of the

Pacific razor clam. In their work the relative growth rate, as initial rate and rate at two years, was correlated with geographical position, age, and length. The factors involved in geographical position are numerous and largely unknown, but include all of the physical and chemical features of the environment.

Geographical position was given a numerical value for correlation by counting the distance along the coast from Pismo, Calif., the most southern beach from which statistically valuable data were gathered. The sign of the correlation, then, is entirely arbitrary.

In order to compare the variations of growth in different localities, as observed in the cockle, with that mentioned above for the razor clam, similar constants were calculated for each locality. The values for geographical position were determined as in the razor clam, the distance being measured from Tillamook. Maximum age and maximum length were obtained as follows: On a survival curve for each locality the age was located at which 5 per cent of the clams passing through the first winter were still alive. This was taken as the maximum age. Owing to the small numbers of cockles available for some localities, this value is only a rough approximation, but the errors involved are much less than the differences in length of life. The maximum length is that length read from the absolute growth curve at the maximum age as just defined.

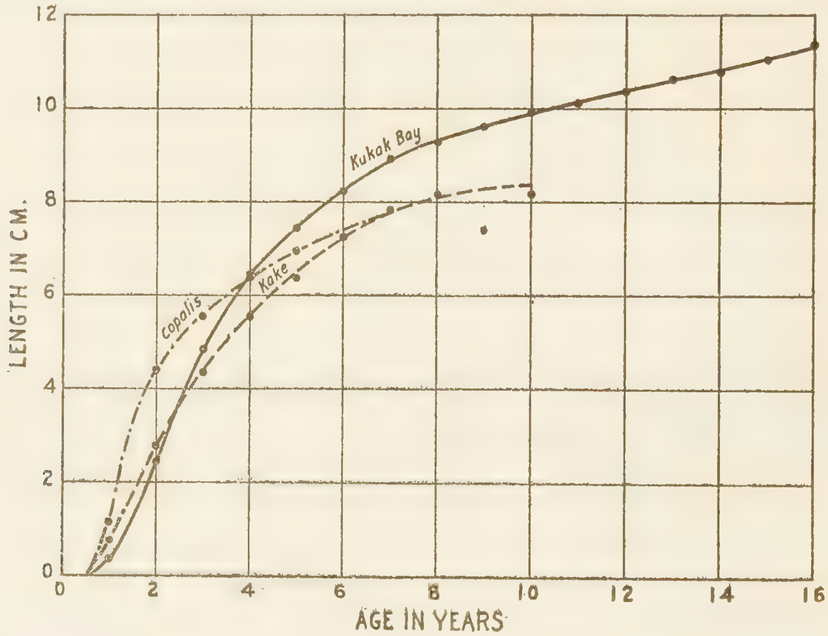

FIGURE 7.—Growth curves of *Cardium corbis* from three localities

The relative growth rate and acceleration were derived from the natural logarithms of the length as discussed earlier in the paper. These five constants for the eight localities are given in Table 2. It should be mentioned that Constantine Harbor and Port Moller do not represent normal habitats for *Cardium*. The beach at the former place is of coarse gravel, and Port Moller is near the northern limit of the species.

TABLE 2.—*Growth constants for different localities*

Locality	Distance, miles	Maximum age, years [1]	Maximum length, centimeters	P_L[2]	Acceleration [3]	Locality	Distance, miles	Maximum age, years [1]	Maximum length, centimeters	P_L[2]	Acceleration [3]
Tillamook	0	7.5	8.15	0.515	−0.497	Constantine Harbor	1,500	11.4	7.30	1.051	−1.342
Copalis	100	6.8	7.60	.515	−.986	Snug Harbor	1,800	--------	--------	1.076	−.603
Kake	1,000	--------	--------	.727	−.889	Kukak Bay	1,940	14.8	10.90	1.127	−1.285
Cordova	1,480	12.4	9.60	1.235	−1.207	Port Moller	2,240	15.2	7.40	.727	−1.363

[1] Actual ring number; to obtain age substract approximately one-half year.

[2] P_L=relative growth rate$=\frac{d \log L}{dt}$ at $t=2$.

[3] Acceleration$=\frac{dP_L}{dt}$.

Scatter diagrams prepared from these data show, in most cases, definite trends that agree with the correlations obtained for the razor clam. (Weymouth, McMillin, and Rich, 1930; Weymouth and McMillin, 1930.)

As in the razor clam, geographical position shows the highest correlation with maximum age. A lower correlation was obtained between length and age. Cockles from the northern beaches reach the greatest ages and largest sizes. The relative growth rate at two years shows a high positive correlation with age and with length. This agrees with the relation shown by razor-clam growth in which a high relative growth rate at two years is associated with great age and large size. The reverse correlations must exist between early growth rate, age, and length. Figure 7 clearly shows this relation to be true in the growth of the cockle. A high positive correlation between age and length is also shown. The cockles reaching the greatest age are the largest.

In the razor clam a confirmation of the relations observed between localities was obtained by comparing the growth of the sexes. (Weymouth, McMillin, and Rich, 1930.) In the case of *Cardium*, such a check is impossible, as the cockle is hermaphroditic. (Edmondson, 1920.)

CONCLUSIONS

In summarizing, it may be said that, although based on a relatively small amount of material incidentally collected, this study of *Cardium* presents several interesting features.

1. The ring method of age determination may be applied to this species as well as to others previously studied.

2. The growth of *Cardium* is characterized by great regularity, as shown by the individual growth curves presented.

3. The type of growth observed in the razor clam is found in the cockle. In this form the relative growth rate falls throughout postlarval life as first noted by Minot in the guinea pig. The decline is orderly and regular, and in most cases the growth curve can be accurately fitted from the formula $L=Be^{-ce^{-kt}}$, based on an exponential rate of decline of the relative growth rate.

4. A comparison of growth in different localities shows the same relations as observed in the razor clam. The northern forms, in contrast to the southern, show a slower initial but more sustained growth and reach the greater age and larger size.

TABLE 3.—*Average length of cockles*

[N=number of individuals; Mi=median length in centimeters; P. E.=probable error of median]

Ring No.	N	Mi	P. E.
TILLAMOOK			
1	23	2.02	0.031
2	17	4.65	.112
3	11	6.06	.281
4	10	7.13	0.264
5	4	7.25	--------
6	2	8.26	--------
7	1	8.10	--------
COPALIS			
1	47	1.14	.077
2	50	4.40	.040
3	22	5.52	.213
4	15	6.36	.104
5	7	6.97	.089
6	3	7.25	.058
7	3	7.85	.058
KAKE			
1	4	.73	--------
2	4	2.78	--------
3	4	4.35	--------
4	4	5.52	--------
5	4	6.37	--------
6	3	7.32	--------
7	3	7.81	--------
8	3	8.15	--------
9	2	7.37	--------
10	1	8.15	--------
CORDOVA			
1	16	.26	.017
2	32	1.80	.191
3	30	3.73	.062
4	30	5.83	.053
5	27	6.68	.140
6	23	7.43	.102
7	8	7.59	.237
CORDOVA—con.			
8	7	8.11	0.147
9	7	8.42	.147
10	6	8.89	--------
11	4	9.21	--------
12	3	9.42	--------
13	2	9.82	--------
14	1	9.70	--------
15	1	9.81	--------
16	1	9.97	--------
17	1	10.03	--------
CONSTANTINE HARBOR			
1	34	.50	.039
2	107	1.80	.099
3	105	3.38	.036
4	81	4.59	.043
5	65	5.41	.055
6	44	5.89	.020
7	36	6.28	.051
8	22	6.60	.082
9	14	6.84	.126
10	11	6.93	.112
11	6	7.27	--------
12	5	7.44	--------
13	1	7.20	--------
SNUG HARBOR			
1	1	.34	--------
2	6	1.09	.502
3	6	2.92	.239
4	5	4.96	.528
5	5	6.54	.297
6	5	7.52	.214
7	5	8.27	.216
8	5	8.75	.434
9	3	8.95	--------
10	2	9.09	--------
11	1	8.80	--------
KUKAK BAY			
1	72	0.34	0.015
2	92	2.44	.040
3	92	4.85	.081
4	81	6.44	.055
5	69	7.45	.093
6	47	8.23	.116
7	34	8.90	.098
8	29	9.31	.045
9	21	9.60	.062
10	14	9.90	.063
11	8	10.10	.063
12	7	10.35	.088
13	6	10.60	.082
14	5	10.75	.075
15	5	11.06	.199
16	4	11.35	.199
PORT MOLLER			
1	18	.39	.020
2	29	2.30	.364
3	20	3.47	.101
4	16	3.60	.135
5	14	5.50	.627
6	13	5.62	.304
7	11	5.75	.558
8	11	6.25	.558
9	9	6.19	.202
10	8	6.54	.237
11	5	6.77	--------
12	2	8.03	--------
13	2	8.21	--------
14	2	8.35	--------
15	2	8.46	--------
16	1	8.73	--------

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STATISTICAL REVIEW OF THE ALASKA SALMON FISHERIES. PART II: CHIGNIK TO RESURRECTION BAY[1]

⁂

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INTRODUCTION

In the first paper of this series [2] a general account was given of the sources and nature of the data dealt with and of the methods used. These statements are equally applicable to the data presented in this report, but it has not been thought necessary to repeat them here. The general plan has been followed of considering the various districts in their geographical order from west to east and the more important localities are shown on the accompanying maps, Figures 1 and 9. Minor localities not shown on the maps will be described in the appropriate places. In order to make uniform the review as a whole there has been given only the data up to and including 1927, the last year treated in Part I. Data for 1928 and 1929 are available for the localities treated in this report, but have not been included since it is planned to bring the entire series up to date at approximately 5-year intervals. The authors will be grateful for information as to errors that may be discovered in any of these reports or for additional facts that will aid in interpreting the data.

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[1] Submitted for publication June 13, 1930.

[2] Statistical Review of the Alaska Salmon Fisheries. Part I: Bristol Bay and the Alaska Peninsula, by Willis H. Rich and Edward M. Ball. Bulletin, U. S. Bureau of Fisheries, Vol. XLIV, 1928, pp. 41–95, 20 figs., Washington, 1928. Bureau of Fisheries Document No. 1041.

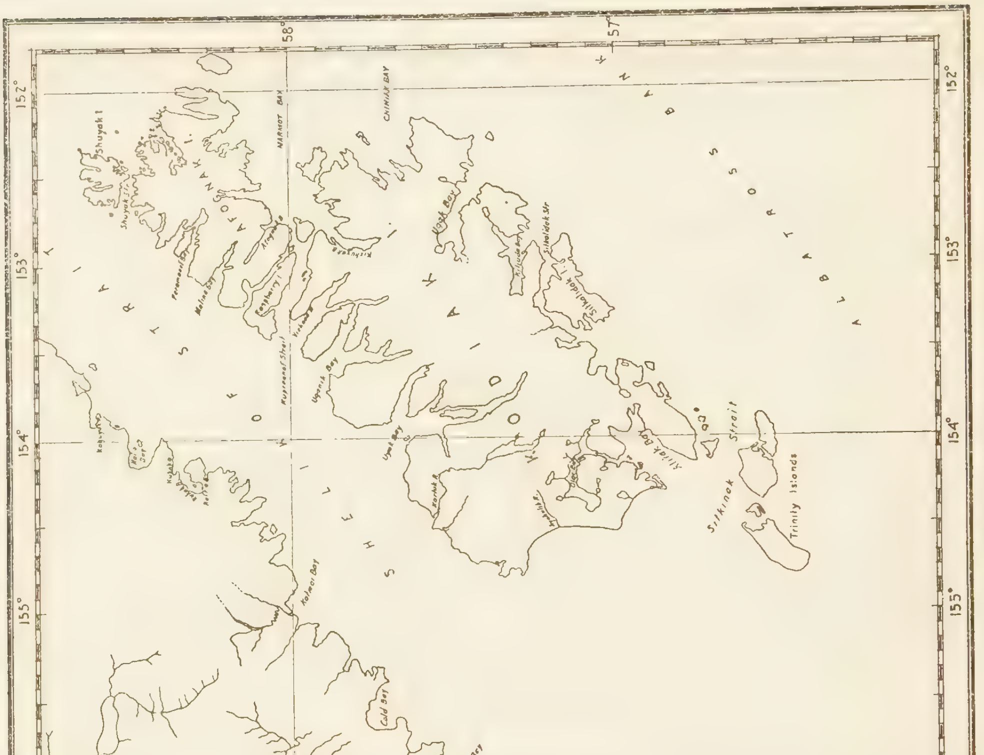
152°
153°
154°
155°
156°
157°
158°
58°
57°
Shuyak I.
AFOGNAK I.
MARMOT BAY
CHINIAK BAY
Ugak Bay
Kiliuda Bay
Sitkalidak Str.
Sitkalidak I.
KODIAK I.
Uyak Bay
Uganik Bay
Raspberry I.
Kupreanof Strait
Alitak Bay
Sitkinak Strait
Sitkinak
Trinity Islands
ALBATROSS BANK
SHELIKOF STRAIT
Kukak
Katmai
Kaguyak
Kashvik
Cold Bay
Puale Bay
Wide Bay
NAKNEK L.
BECHAROF LAKE
UGASHIK LAKES
PENINSULA
ALASKA
SEMIDI ISLANDS
Amber Bay
Aniakchak Bay
Kujulik Bay
C. Kumlium
Chignik Bay
CHIGNIK BAY
KVICHAK BAY
BRISTOL BAY
NUSHAGAK BAY

FIGURE 1.—Map of eastern end of the Alaska Peninsula and the Kodiak group of islands

CHIGNIK

The salmon fishery at Chignik began in 1888 when 2,160 barrels of salted salmon were packed. In 1889 canning operations were begun and have been continued without interruption to the present time. A few fish have been salted at various times but the bulk of the catch has been canned. The fishery has been restricted to a relatively small area within a few miles of the mouth of Chignik River and draws mainly upon the runs of salmon which spawn in this stream. As a result, the fishery has been very intense, and the competition between the several operating companies was keen. After various changes in the companies the situation finally became stabilized in 1914 when the three companies then operating—the Alaska Packers Association, the Columbia River Packers Association, and the Northwestern Fisheries Co.—agreed to an equal division of the catch. This resulted in a much more efficient conduct of the fishery, although its intensity and the drain upon the runs was to no extent reduced. There has been no material change in the fishery since that time except as effected by the regulations imposed under the authority given in 1922 by the Executive order establishing the Alaska Peninsula Fisheries Reservation and the act of June 6, 1924. (See Part I, pp. 51 and 52.)

No regulations of consequence were imposed in 1922. In this year, however, a counting weir was established in the Chignik River for the purpose of ascertaining the number of salmon that escaped from the commercial fishery and passed on to the spawning grounds. This weir has since played an important part in the control of the fishery, as will be seen. In 1922 the escapement was 428,976 red salmon, 58,300 cohos, and 241 kings. Pinks and chums were not counted, but the escapement was estimated at 15,000 and 1,200 respectively. The commercial catch of red salmon in 1922 consisted of 1,403,701 fish, 76.6 per cent of the total run. In 1923 the catch and the escapement were both so low that commercial fishing was stopped on August 21, but in spite of this the catch was again in excess of 75 per cent of the total run. The act of June 6, 1924, specifically required an escapement of not less than 50 per cent of the run "in streams where counting weirs are maintained," and this has materially affected the commercial fishery. Furthermore, beginning with 1925 it has been required that the minimum escapement shall be not less than 1,000,000 and this requirement has been practically met in each subsequent year. These regulations have had a marked effect upon the catch, and it will be necessary to bear them in mind in order to interpret properly the fluctuations in the catch that appear in the table.

In the earlier years, the fishery at Chignik was confined exclusively to Chignik Bay and Chignik Lagoon. In 1913 a small catch was made in Hook Bay, and in 1917 operations were extended to include Aniakchak and Kujulik Bays (fig. 1). The catch in these three minor districts has been largely composed of pinks, chums, and cohos, and this extension of the Chignik fishery was interrupted in 1921 owing to the depressed market for the cheaper grades of canned salmon. (See p. 43, Part I.) It was resumed again in 1924 and has continued to the present time.

The figures for the salmon catch at Chignik are given in Table 1. The data for the years 1888 to 1904, inclusive, have been adapted from Moser[3] and from the various reports of the Treasury agents on the salmon fisheries of Alaska for the years 1892 to 1904.[4]

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[3] The Salmon and Salmon Fisheries of Alaska, by Jefferson F. Moser. Bulletin, U. S. Fish Commission, Vol. XVIII, 1898 (1899), pp. 1-178, Washington.

Alaska Salmon Investigations in 1900 and 1901, by Jefferson F. Moser. Bulletin, U. S. Fish Commission, Vol. XXI, 1901 (1902), pp. 173-398, Washington.

[4] These reports appeared regularly, except for 1893, during the interval covered and were published as Treasury Department, Senate and House Documents. The one for the year 1892 was by Max Pracht; those for 1894 and 1895 by Joseph Murray; that for 1896 by George R. Tingle, and those for the years 1894 to 1904, inclusive, by Howard M. Kutchin.

TABLE 1.—*Salmon catch and fishing apparatus used in the Chignik Bay district, 1888 to 1927*

Year	Coho	Chum	Pink	King	Red	Traps
Aniakchak Bay:						
1917	405	19, 521	1, 948	100	30, 162	
1918	2, 017	41, 903	142, 568	216	48, 299	
1919	10, 492	27, 990	1, 265		16, 181	
1920	1, 065	4, 099	39, 903		3, 550	
1924	2, 855	4, 205	122, 926		[1] 17, 641	
1925	10, 055	11, 900	20, 954		10, 977	
1926	19, 097	77, 183	275, 960	44	67, 530	
1927	11, 416	27, 025	33, 070	103	21, 459	
Chignik Bay and Lagoon:						
1888					13, 000	
1889					560, 000	
1890					453, 000	
1891					775, 000	
1892					522, 000	
1893	64, 000				600, 000	
1894					600, 000	
1895					683, 319	
1896	56, 764			3, 304	850, 000	
1897	10, 510		5, 800		765, 000	
1898	790	850			1, 165, 419	
1899	12, 882		[2] 18, 134		903, 749	
1900	2, 053	1, 200	[3] 52, 350		1, 047, 371	
1901	6, 510		40, 484		907, 350	
1902					1, 782, 015	
1903	8, 616		84, 097		1, 149, 990	
1904			27, 785	129	1, 689, 642	
1905					1, 297, 114	
1906					1, 323, 584	
1907	800				1, 622, 987	
1908					1, 630, 677	
1909					1, 730, 804	
1910	36, 907		17, 170		1, 314, 672	
1911	7, 788	14, 788	23, 128		1, 077, 595	
1912	18, 979	14, 032	55, 099	33	1, 330, 832	
1913	23, 773	84, 341	29, 488	1, 918	825, 766	
1914	34, 475	32, 388	80, 080	320	1, 056, 629	
1915	29, 617	65, 350	55, 665	1, 054	1, 330, 031	
1916	45, 899	88, 778	267, 148	1, 693	1, 002, 911	
1917	12, 769	54, 384	5, 603	715	1, 425, 552	
1918	19, 101	233, 782	188, 293	1, 233	1, 494, 408	
1919	24, 439	70, 008	3, 542	597	868, 757	
1920	21, 428	141, 590	248, 257	811	1, 769, 160	
1921	13, 251	220, 721	30, 620	399	1, 828, 857	
1922	14, 952	212, 789	359, 510	500	1, 248, 763	
1923	18, 574	84, 375	8, 967	867	642, 872	
1924	91, 330	94, 915	638, 947	477	856, 389	
1925	18, 027	69, 127	13, 453	1, 297	693, 786	
1926	10, 688	103, 503	234, 571	534	415, 214	
1927	85, 512	108, 185	145, 472	813	432, 346	
Hook Bay:						
1913		6, 811	592		7, 454	
1924	248	8, 673	238, 119	6	3, 313	
1925	1, 967	14, 298	7, 297	178	7, 833	
1926	2, 057	20, 181	125, 848	252	26, 599	
1927	4, 468	19, 888	6, 933	70	1, 795	
Kujulik Bay:						
1917	149	34, 045	2, 032	89	752	
1918		31, 033	13, 609			
1919		26, 965				
1920		6, 517	9, 666			
1924		3, 000				
1925		6, 796			62	
1926		64, 301	40, 647		1, 375	
1927	26	16, 369	1, 235	1	663	
Total:						
1888					13, 000	
1889					560, 000	
1890					453, 000	
1891					775, 000	
1892					522, 000	
1893	64, 000				600, 000	
1894					600, 000	
1895					683, 319	
1896	56, 764			3, 304	850, 000	
1897	10, 510		5, 800		765, 000	
1898	790	850			1, 165, 419	
1899	12, 882		[2] 18, 134		903, 749	
1900	2, 053	1, 200	[3] 52, 350		1, 047, 371	23
1901	6, 510		40, 484		907, 350	21
1902					1, 782, 015	21
1903	8, 616		84, 097		1, 149, 990	29
1904			27, 785	129	1, 689, 642	28
1905					1, 297, 114	12
1906					1, 323, 584	7
1907	800				1, 622, 987	8

[1] 10,000 allocated arbitrarily from a catch of 40,294 recorded only as from Chignik Bay and Aniakchak Bay.
[2] Recorded by Kutchin but not by Moser.
[3] Mixed pinks and chums according to Moser.

TABLE 1.—*Salmon catch and fishing apparatus used in the Chignik Bay district, 1888 to 1927*—Con.

Year	Coho	Chum	Pink	King	Red	Traps
Total—Continued.						
1908	------	------	------	------	1,630,677	8
1909	------	------	------	------	1,730,804	8
1910	36,907	------	17,170	------	1,314,672	18
1911	7,788	14,788	23,128	------	1,077,595	29
1912	18,979	14,032	55,099	33	1,330,832	37
1913	23,773	91,152	30,080	1,918	833,220	37
1914	34,475	32,388	80,080	320	1,056,629	9
1915	29,617	65,350	55,665	1,054	1,330,031	9
1916	45,899	88,778	267,148	1,693	1,002,911	9
1917	13,323	107,950	9,583	904	1,456,466	12
1918	21,118	306,718	344,470	1,449	1,542,707	12
1919	34,931	124,963	4,807	597	884,938	14
1920	22,493	152,206	297,826	811	1,772,710	12
1921	13,251	220,721	30,620	399	1,828,857	9
1922	14,952	212,789	359,510	500	1,248,763	9
1923	18,574	84,375	8,967	867	642,872	9
1924	94,433	110,793	999,992	483	877,343	9
1925	30,049	102,121	42,704	1,475	712,658	9
1926	31,842	265,168	677,026	830	510,718	10
1927	101,422	171,467	186,710	987	456,263	10

NOTE.—No catches were reported in the years not shown. Kujulik Bay is locally known as Sitkum Bay.

Moser's figures for the years up to and including 1897 give only total case packs and are not segregated by species. The data for 1898 to 1900 give the pack by species and also the average number of fish per case, so that it is possible to estimate the catch with a fair degree of accuracy. The reports of the Treasury agents have also been consulted and the data compared carefully with those given by Moser. These reports show the number of fish caught, and these data have been used when they checked with Moser's figures for the pack. In cases where the two series of data did not check we have assumed Moser's to be the more reliable and have calculated the catch from the pack. The data for the later years, beginning with 1904, have come from the sworn statements submitted yearly to the Bureau of Fisheries by the several companies.

The transfer of fish from one locality to another was a common practice in western Alaska until recently, when it was stopped by regulation. Such transfers were frequently made back and forth between the Chignik canneries and those at Karluk and Alitak and have occasioned a great deal of confusion in the records. Great care has been taken in trying to eliminate errors from this cause and it is believed that the data are fairly well segregated. It is possible, however, that there is still some slight confusion. Another difficulty has been encountered in some of the more recent records due to the agreement between the three companies operating at Chignik to divide the catch equally. The statements submitted by these companies do not always agree; some of the statements are apparently based on the catch made by the particular company regardless of its final disposition, others show the catch and also the deliveries and receipts to and from other companies, and still others show the fish packed regardless of the source. If the procedure has been uniform, any one of the systems would have provided us with the desired data but, unfortunately, this was not the case. The chief difficulty encountered has to do with the allocation of the catch to the several subdistricts, Chignik proper, Aniakchak, Kujulik, and Hook Bays. The statements of the several companies have been very carefully examined and some additional information has been secured by correspondence. In spite of the greatest care it has been necessarry to allocate certain catches arbitrarily, but it is felt that no serious errors have resulted. The totals for the whole district are considered sufficiently reliable for the practical purposes to which they may be put.

RED SALMON

The red salmon of this district are derived almost exclusively from the Chignik River. It is possible that a few fish, especially of those caught in Aniakchak Bay, come from smaller streams near by, but the Chignik runs dominate so largely that we have considered the total catch of the district as a unit and refer it exclusively to the Chignik River. Figure 2 shows graphically the total annual catches of red salmon. It will be seen that the fishery shows much the same history as some of the districts discussed in Part I; namely, a period of gradual growth to a maximum which is maintained for a time but is eventually followed by a drop in productivity and the incidence of wider fluctuations which are indicative of depletion. The lowered level of productivity since 1924 is due in part to the regulations which have required an increased escapement as measured by the weir count. Such an increased escapement was necessary to prevent further depletion and to provide for the upbuilding of the run to the level of greatest productivity, but it has, necessarily, decreased the commercial catch. As the runs build up to a more healthy state the commercial catch will naturally increase again, and it may be presumed that, as conditions warrant, some of the present restrictions can be gradually removed.

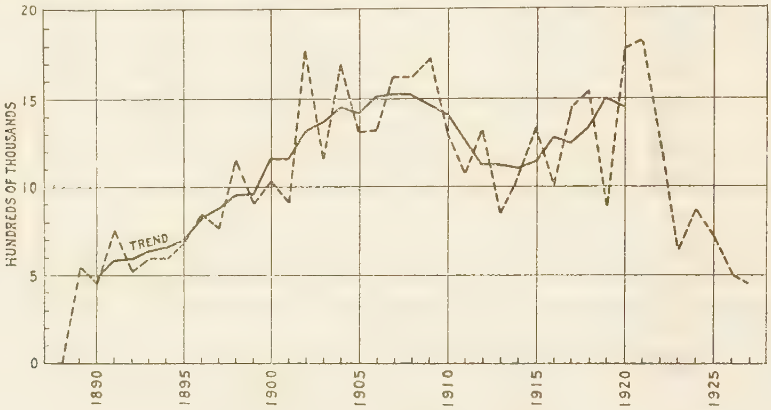

FIGURE 2.—Catch of red salmon at Chignik

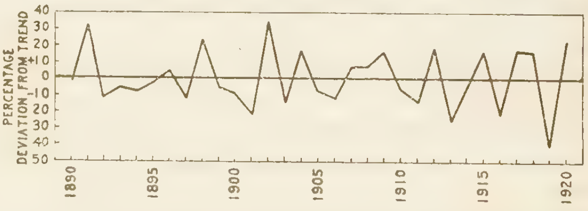

FIGURE 3.—Percentage fluctuation from the trend of the catch of red salmon at Chignik

It is interesting to note the character of the deviations from the trend shown by the Chignik catches. The trend shown in Figure 2 has been calculated in the same way as the trends in the previous report and represents a moving average by fives. (See p. 61, Part I.) Figure 3 shows the percentage deviations from this trend. A comparison with the similar graphs (showing the percentage deviations from the trends in Bristol Bay, p. 63, Part I) shows, in the case of Chignik, a complete lack of the definite periodicity of fluctuations that is such a conspicuous feature in the other districts. At Chignik the fluctuations about the trend are much less violent (the greatest is 41 per cent), and the maxima and minima come at very irregular intervals. It would be difficult to explain this condition were it not for the fortunate fact that recently secured data show that the Chignik red-salmon runs do not consist so predominantly of fish of a single age group. Harlan B. Holmes, assistant aquatic biologist, is now engaged in an intensive study of these fish and has found relatively high percentages of 4, 5, and 6 year fish in the commercial catches. While the study is too incomplete to warrant definite conclusions, the indications are that, while the 5-year fish usually predominate, they form, on the average, only about 50 per cent of the total run. Approximately 20 per cent are 4-year fish, and 30 per cent are 6-year fish. Such a condition would inevitably bring about a lack of the definite periodicity that is characteristic of runs in which a single age group is strongly predominant, and it would also tend to smooth out the fluctuations so that they would not be so extreme. It seems very probable that this is the explanation of the peculiar character of the deviations from the trend shown in Figure 3.

OTHER SPECIES

The catches of the other species of salmon, especially pinks, chums, and cohos, are not derived so largely from the Chignik runs but include fish derived from smaller streams entering Aniakchak, Kujulik, and Hook Bays. These districts were not regularly fished previously to 1917, and the effect of this development is clearly apparent in the records of the catches of these three species. The catches of all the cheaper grades of salmon were irregular previous to about 1910 or 1912, so that attempts at analyses have been limited to the subsequent years. The data are shown graphically in Figure 4.

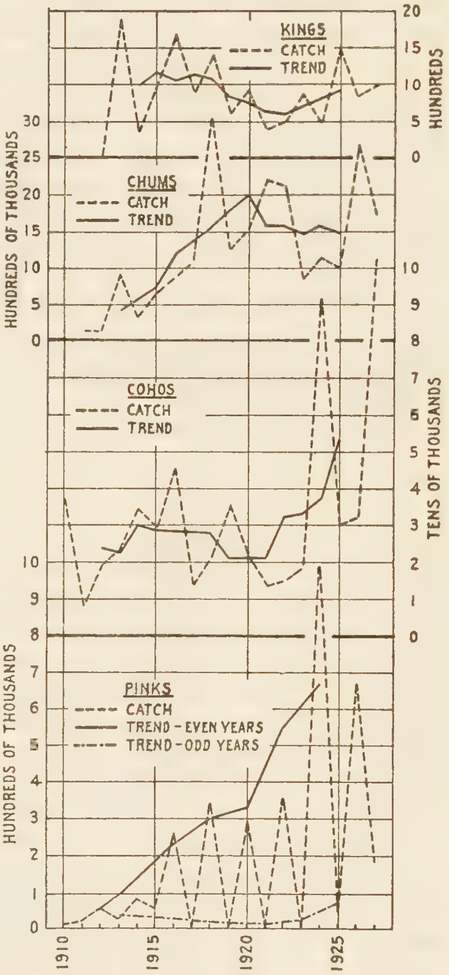

FIGURE 4.—Catch of kings, chums, cohos, and pinks at Chignik

The pink salmon show the characteristic 2-year cycle with large runs on the even years and small runs on the odd. The trend of the catches in the even years (moving average by threes) shows a steady rise which, however, is affected greatly by the very large catches of 1924 and 1926. In order to show more clearly, and to some extent graphically, the nature of the changes in the catch of pinks, Table 2 is presented which shows for each year the extent to which fish from each locality entered into the total catch. It is apparent from this that the heavy catches of 1924 and

1926 were the result of exceptionally good runs at Aniakchak and Hook Bays. The catch of 1924 in Chignik Bay was indeed unusually good and when the catches at Aniakchak and Hook Bays are added we have the very high total catch noted. The catch in Chignik Bay fell off again, however, in 1926, although the good catches in the other localities held up the total catch for the district to a level approximately that of 1924. The recent increase in the catch of pinks in the Chignik district, therefore, is seen to be due to the extension of the fishery to new grounds, and it does not seem probable that the increase will continue unless there is further extension of the fishery to include other districts that produce pink salmon. The catches in the odd years have been insignificant except in 1927 when there was a very good catch of over 180,000 fish in Chignik Bay alone. The catches in the other localities were, however, not much, if any, greater than normal so that, whatever affected the catch in Chignik Bay, it seems probable that similar conditions did not obtain in other near-by places. This increased catch of pinks at Chignik in 1927 may indicate that the odd-year runs are "building up" or it may be the result of some change in the fishing intensity for this species which the authors have been unable to trace.

Table 2.—*Graphic table of catches of pink salmon in Chignik district*

[Each letter represents a catch of 20,000 fish except that fractional parts of this unit catch are considered as full units. Thus any catch up to 20,000 will be represented by a letter; any catch between 20,000 and 40,000 will be represented by two letters, etc. The letter "B" indicates the catch in Chignik Bay and Lagoon; "A" the catch at Aniakchak; "E" the catch at Hook Bay; and "G" the catch at Kujulik]

Year	Catch
1910	B
1911	BB
1912	BBB
1913	BBE
1914	BBBBB
1915	BBB
1916	BBBBBBBBBBBBBB
1917	BA
1918	BBBBBBBBBBAAAAAAAAG
1919	BAG
1920	BBBBBBBBBBBBBAAG
1921	BB
1922	BBBBBBBBBBBBBBBBBB
1923	B
1924	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBAAAAAAAEEEEEEEEEEEE
1925	BAAE
1926	BBBBBBBBBBBBAAAAAAAAAAAAAAEEEEEEEGGG
1927	BBBBBBBBAAEG

The catch of cohos is shown graphically in Figure 4 and also in Table 3. Throughout the period under discussion the catch in Chignik Bay has been by far the most important and was exceeded only in 1926 by the catch at Aniakchak. The trend was generally downward between 1910 and 1923, but remarkable catches were made in both 1924 and 1927. The poor catches of 1921 and 1923 were undoubtedly due, at least in part, to the poor market for the cheaper grades of salmon that prevailed at that time, and this has affected the trend. In spite of the general downward tendency up to 1924 it seems doubtful that any real depletion had taken place; the sudden increase in 1924 to a level more than twice as high as that of any previous year would certainly indicate that the spawning reserves were adequate to produce a good run, at least under favorable conditions. It is interesting to note that the peak runs of 1916 and 1924 were followed by other peak runs three years later. This strongly indicates that the Chignik cohos are predominantly 3-year fish although it is known that in some other near-by districts a large proportion of the fish of this species are 4-year fish.

Table 3.—*Graphic table of catches of coho salmon in the Chignik district*

[See Table 2 for explanation. Each letter in this table represents a catch of 2,000 fish]

Year	Catch
1910	BBBBBBBBBBBBBBBBBBB
1911	BBBB
1912	BBBBBBBBBB
1913	BBBBBBBBBBBB
1914	BBBBBBBBBBBBBBBBBB
1915	BBBBBBBBBBBBBBB
1916	BBBBBBBBBBBBBBBBBBBBBBB
1917	BBBBBBBAG
1918	BBBBBBBBBBAA
1919	BBBBBBBBBBBBBAAAAAA
1920	BBBBBBBBBBBA
1921	BBBBBBB
1922	BBBBBBBB
1923	BBBBBBBBBB
1924	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBAE
1925	BBBBBBBBBBAAAAAAE
1926	BBBBBBAAAAAAAAAAEE
1927	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBAAAAAEEEG

Considering the Chignik district as a whole the catch of chums, as shown in Figure 4, gradually increased until about 1918 and has since maintained a fairly constant level. Table 4, however, shows that this level has been maintained by large catches made at Aniakchak, Hook, and Kujulik Bays particularly in 1926 and 1927. The average annual catch in Chignik Bay alone was approximately twice as great during the period from 1918 to 1922, inclusive, as it has been at any time since. It is probable, however, that the regulations have affected the catch of chums as they did the catch of reds so that the lowered productivity since 1922 can not be taken as evidence of depletion.

Table 4.—*Graphic table of catches of chum salmon in the Chignik district*

[See Table 2 for explanation. Each letter in this table represents a catch of 5,000 fish]

Year	Catch
1910	
1911	BBB
1912	BBB
1913	BBBBBBBBBBBBBBBBBEE
1914	BBBBBBB
1915	BBBBBBBBBBBBBB
1916	BBBBBBBBBBBBBBBBBB
1917	BBBBBBBBBBBAAAAGGGGGGG
1918	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBAAAAAAAAAGGGGGGG
1919	BBBBBBBBBBBBBBBAAAAAAGGGGGG
1920	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBAGG
1921	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
1922	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
1923	BBBBBBBBBBBBBBBBB
1924	BBBBBBBBBBBBBBBBBBBAEEG
1925	BBBBBBBBBBBBBBAAAEEEGG
1926	BBBBBBBBBBBBBBBBBBBBBAAAAAAAAAAAAAAAAEEEEEGGGGGGGGGGGGG
1927	BBBBBBBBBBBBBBBBBBBBBBAAAAAAEEEEGGGG

Table 5.—*Graphic table of catches of king salmon in the Chignik district*

[See Table 2 for explanation. Each letter in this table represents a catch of 50 king salmon]

Year	Catch
1912	B
1913	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
1914	BBBBBBB
1915	BBBBBBBBBBBBBBBBBBBBBB
1916	BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
1917	BBBBBBBBBBBBBBBAAG
1918	BBBBBBBBBBBBBBBBBBBBBBBBBAAAAA
1919	BBBBBBBBBBBB
1920	BBBBBBBBBBBBBBBBB
1921	BBBBBBBB
1922	BBBBBBBBBB
1923	BBBBBBBBBBBBBBBBBB
1924	BBBBBBBBBBE
1925	BBBBBBBBBBBBBBBBBBBBBBBBBBEEEE
1926	BBBBBBBBBBBAEEEEEE
1927	BBBBBBBBBBBBBBBBBAAAEEG

The king salmon constitute a relatively unimportant element in the salmon catch at Chignik. The annual catch has never exceeded 2,000 fish, and the average is less than 1,000. The average catch was relatively low from 1919 to 1924, but since then has been about the same as in the earlier years. It seems probable that the fluctuations are due chiefly to chance or to temporary fluctuations in abundance that can not be definitely assigned to depletion.

SHELIKOF STRAIT

The Shelikof Strait district includes the waters of the Alaska Peninsula between Cape Douglas and Cape Providence. The data are presented in Table 6.

Until 1918, the only salmon fishery in the district was at Kaflia Bay, where the earliest recorded catch was made in 1909. However, this bay had been visited occasionally before 1900 by fishermen from Karluk when the run at that place was slack. Excursions of this kind were not uncommon, and discoveries were thus made of salmon streams in outlying districts. The fish caught on such cruises were taken to the canneries at Karluk and Uyak Bay and counted as Karluk salmon. Therefore, no records are known to the bureau that give any conception of the number of fish taken at Kaflia Bay before 1909, or that indicate the year in which operations first began. Authentic statistics of catches were obtainable only after the saltery was opened in 1909. From then until 1924, the figures are presumed to be complete. Since 1924, commercial fishing in Kaflia Bay has been prohibited.

TABLE 6.—*Salmon catch and fishing appliances used in the Shelikof Strait district, 1909 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Douglas, Cape: 1919	--------	2, 500	4, 500	--------	--------	--------	--------	--------	--------	--------	--------	--------
Douglas Island: 1919	600	4, 000	3, 900	233	6, 125	--------	--------	--------	--------	--------	--------	--------
Hallo Bay: 1927	--------	1, 228	1, 865	--------	--------	--------	--------	--------	--------	--------	--------	--------
Kaflia Bay:												
1909	--------	--------	--------	--------	45, 088	--------	--------	--------	--------	--------	--------	--------
1910	--------	--------	--------	--------	33, 827	--------	--------	--------	--------	--------	--------	--------
1911	--------	--------	--------	--------	56, 958	--------	--------	--------	--------	--------	--------	--------
1912	--------	--------	456	--------	70, 303	--------	--------	--------	--------	--------	--------	--------
1913	--------	--------	--------	--------	84, 462	--------	--------	--------	--------	--------	--------	--------
1914	--------	--------	--------	--------	41, 367	--------	--------	--------	--------	--------	--------	--------
1915	--------	--------	--------	--------	4, 628	--------	--------	--------	--------	--------	--------	--------
1916	--------	--------	--------	--------	443	--------	--------	--------	--------	--------	--------	--------
1917	--------	--------	--------	--------	335	--------	--------	--------	--------	--------	--------	--------
1919	--------	--------	--------	--------	296	--------	--------	--------	--------	--------	--------	--------
1921	--------	--------	--------	--------	894	--------	--------	--------	--------	--------	--------	--------
1922	--------	--------	--------	--------	1, 971	--------	--------	--------	--------	--------	--------	--------
1923	--------	1	11	--------	10, 747	--------	--------	--------	--------	--------	--------	--------
1924	--------	--------	--------	--------	9, 429	--------	--------	--------	--------	--------	--------	--------
Kiukpalik Island: 1927	612	2, 273	12, 291	172	1, 458	--------	--------	--------	--------	--------	--------	--------
Scharck Lagoon: 1924	6, 640	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Unallocated:												
1925	6, 057	300	4, 024	--------	1, 827	--------	--------	--------	--------	--------	--------	--------
1926	2, 724	3, 090	10, 910	--------	9, 377	--------	--------	--------	--------	--------	--------	--------
1927	10, 782	885	8, 915	--------	10, 251	--------	--------	--------	--------	--------	--------	--------
Total:												
1909	--------	--------	--------	--------	45, 088	--------	--------	--------	--------	--------	--------	--------
1910	--------	--------	--------	--------	33, 827	--------	--------	--------	--------	--------	--------	--------
1911	--------	--------	--------	--------	56, 958	--------	--------	--------	--------	--------	--------	--------
1912	--------	--------	456	--------	70, 303	6	600	--------	--------	2	150	--------
1913	--------	--------	--------	--------	84, 462	2	200	--------	--------	2	130	--------
1914	--------	--------	--------	--------	41, 367	2	180	--------	--------	4	272	--------
1915	--------	--------	--------	--------	4, 628	2	150	--------	--------	--------	--------	--------
1916	--------	--------	--------	--------	443	--------	--------	--------	--------	--------	--------	--------
1917	--------	--------	--------	--------	335	--------	--------	--------	--------	--------	--------	--------
1919	600	6, 500	8, 400	233	6, 421	--------	--------	--------	--------	5	300	--------
1921	--------	--------	--------	--------	894	--------	--------	--------	--------	--------	--------	--------
1922	--------	--------	--------	--------	1, 971	1	90	1	200	--------	--------	--------
1923	--------	1	11	--------	10, 747	--------	--------	--------	--------	--------	--------	--------
1924	6, 640	--------	--------	--------	9, 429	1	50	--------	--------	2	50	--------
1925	6, 057	300	4, 024	--------	1, 827	--------	--------	--------	--------	--------	--------	--------
1926	2, 724	3, 090	10, 910	--------	9, 377	--------	--------	1	80	1	90	--------
1927	11, 394	4, 386	23, 071	172	11, 709	2	160	--------	--------	--------	--------	1

NOTE.—No catches were reported in the years not shown in the table. Hallo Bay is also known locally as Wide Bay.

This is mainly a red-salmon fishery, as in the 14 years for which records are available only in 1912 and 1923 has any other species of salmon been taken. A few pinks and one chum were taken in those years. The fishery draws for its supply of red salmon upon a run that breeds in a small stream that enters the head of Kaflia Bay and drains a small lake not far inland. There is no reason to suppose that fish belonging to any other district are taken in the Kaflia Bay fishery.

As a result of the Katmai eruption in 1912 Kaflia Bay and the surrounding country received a heavy covering of volcanic ashes and pumice which entirely stopped the flow of water in many streams. Yet this bay, notwithstanding its proximity to the volcano and central location in the zone most heavily covered with ashes, produced in that year 70,303 red salmon, the largest catch that had then been made and which has been exceeded only by the catch in 1913. It was the more amazing because 80 per cent of the take was made after the eruption, which occurred early in June just when the run was beginning. That the salmon came and remained in the bay waiting for the stream to flow again is certainly a striking manifestation of the homing instinct of the salmon. The conditions in and about the mouth of the stream were observed during the summer of 1912 and were extremely abnormal. The water was very low, due in part to scanty rains, and the meager flow was filled with the finely powdered volcanic ash. Martin in his article on the Katmai eruption [5] quotes a graphic description of the conditions in Kaflia Bay given by Ivan Orloff, a resident of Afognak who was in Kaflia Bay at the time of the eruption. He says in part: "All the rivers are covered with ashes, just ashes mixed with water." The chemical conditions in the stream must have been fully as abnormal as the physical conditions, although nothing is known definitely about this. There is some evidence given by Martin that fumes from the volcano were such that rain was made distinctly acid. On August 15 "rain fell during the middle of the morning. The drops of water striking the eyes produced a sharp pain, and brass and silver were tarnished by the drops." In spite of all these unusual conditions the salmon remained in the bay and apparently held as rigidly to their habit of returning to the parent stream as ever. Extremely modified conditions did not lead them to seek another spawning stream, although it is difficult to imagine how a stream might be more radically changed than by the eruption. Certainly such an incident should give pause to those who would explain the mechanism of the homing "instinct" on relatively simple physico-chemical grounds.

Four years later the catch dropped to 443; in 1917, five years after the eruption, it was still lower, being only 335. In these figures, then, may be found substantial proof of the correctness of the observation that very few salmon spawned successfully in the stream at Kaflia Bay in 1912, and that the small returns in 1916 and 1917 may have been the progeny of salmon that ascended the stream before June 6, 1912, the date of the beginning of the Katmai eruption. This sudden depletion of the run was probably due not alone to the eruption and the consequent destruction of the spawning grounds for that and the next few years, but in part to the heavy inroads that were made into the run by the commercial fishery during the period from 1909 to 1914. During each of these years large catches of red salmon were made, ranging from nearly 34,000 in 1910 to over 84,000 in 1913. The combined effect of the eruption and of this heavy fishing was practically to destroy the run so far as its value as a commerical resource was concerned. Since 1914 very few fish have been taken in Kaflia Bay, although the slightly increased catches of 1923 and 1924 would indicate that the run was building up to some extent. It would seem that a careful and continued study of this run would provide observations of great interest and value in determining the capacity of a run to rehabilitate itself after virtual extermination.

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[5] The Recent Eruption of Katmai Volcano in Alaska. By George C. Martin. The National Geographic Magazine, Vol. XXIV, No. 2, February, 1913.

In the first three years for which we have statistics, Kaflia Bay was fished by one operator who packed from 500 to 900 barrels of red salmon a year. Fishing appliances consisted of small beach seines and short gill nets. A small crew of natives performed all the labor both in the catching and the pickling of the fish. Fishing was far from being intensive, thus permitting a good escapement of spawning fish. Unfortunately for the Kaflia Bay salmon and the packer as well he extended his operations into the Afognak field and devoted most of his time to supervision of these ventures instead of giving undivided attention to the older fishery at Kaflia Bay, where his interests were respected by all packers in the Kodiak area. As a result Uyak Bay fishermen, knowing that the native fishermen at Kaflia, being residents of Afognak, had been returned to their homes on account of the eruption and that the bay had apparently been abandoned, went to Kaflia with their larger seines and literally scooped out the whole school of salmon waiting to ascend the stream. This performance was repeated in 1913 and a catch of 84,462 reds resulted, which is the largest ever taken in that locality. Five years later not a salmon was caught. In 1914 and 1915 the catch was respectively 52 and 94 per cent below the record yield of 1913. In the period from 1916 to 1921 less than 1,000 fish were taken in any year, while in 1918 and 1920 no salmon were caught. In 1923 there was a decided improvement in the run as the catch reached a total of 10,747 reds; this was followed by a drop to 9,429 in 1924. Since then Kaflia Bay has been closed to all commerical fishing for salmon.

In 1924 a clam cannery was opened on Kukak Bay and a small pack of salmon was made in each year to 1927. The fish were obtained in part from localities listed in the table, but mostly from unnamed waters. The catch at Kiukpalik Island in 1927 was made by a trap operated in connection with a cannery at Kodiak, and those in 1919 at Cape Douglas and Douglas Island by gill nets also went to the Kodiak cannery. The unallocated catches of this district came from waters between Cape Douglas and Wide Bay.

KODIAK AND AFOGNAK ISLANDS

ALITAK BAY

The Alitak Bay district includes all the waters of Alitak Bay and its tributaries from Cape Alitak on the west to Cape Trinity on the east. It is a compact district with a fishery distinctively its own, as far as is now known. The data are presented in Table 7; those for the years previous to 1904 were taken from Moser and from the various reports of Treasury agents.

RED SALMON

This fishery was centered for 20 years on Olga Bay red salmon, as in that period no other species was taken except cohos, and then only in six seasons. Fishing began in 1889, when two canneries, one on Olga Bay and the other on Olga Strait, were built and made packs of reds. The latter plant was operated two seasons, and in 1891 it received a share of the pack of the cannery on Olga Bay and was subsequently moved to Karluk, leaving but one cannery in this locality. This situation continued without change until 1918, when a second cannery was established that has continued operations up to the present time.

The recorded catch of red salmon is given graphically in Figure 5. In the 39 years covered by this review, 1889 to 1927, the district has produced an average of over 400,000 red salmon annually. The catch has fallen below 200,000 only three times, the last time in 1923, when only 165,945 fish were taken—the smallest catch on record. In 1917 and in 1921 the catch exceeded 950,000 red salmon, while in seven other years it was more than 500,000. These figures show extraordinary productivity for a district that embraces no stream comparable in size even with Red River, Uganik Creek, or many of the other streams of Kodiak Island.

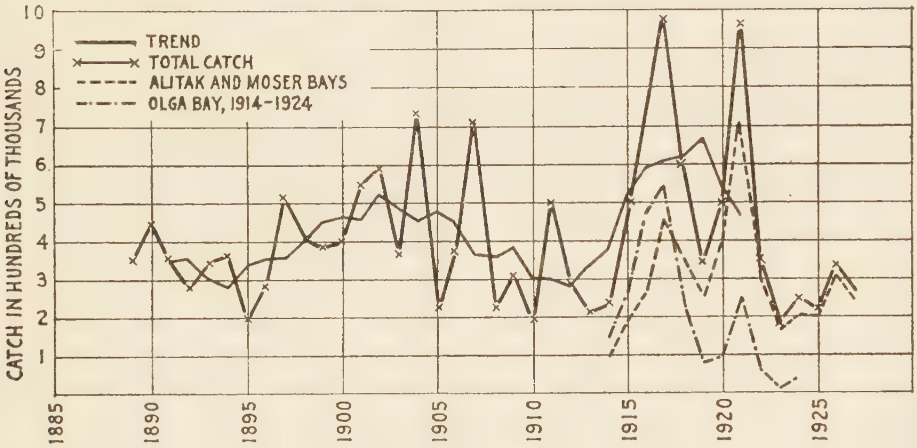

FIGURE 5.—Catch of red salmon at Alitak, Moser, and Olga Bays

TABLE 7.—*Salmon catch and fishing appliances used in the Alitak Bay district, 1889 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Alitak and Moser Bays:												
1914	4,000	3,000	90,000	--------	90,000	--------	--------	--------	--------	--------	--------	--------
1915	7,000	6,000	26,000	--------	180,000	--------	--------	--------	--------	--------	--------	--------
1916	597	4,598	72,264	--------	257,510	--------	--------	--------	--------	--------	--------	--------
1917	2,025	2,169	2,458	--------	443,382	--------	--------	--------	--------	--------	--------	--------
1918	17,428	16,627	542,166	747	341,352	--------	--------	--------	--------	--------	--------	--------
1919	52,126	16,340	32,521	--------	248,756	--------	--------	--------	--------	--------	--------	--------
1920	47,287	40,349	514,262	--------	396,947	--------	--------	--------	--------	--------	--------	--------
1921	22,972	19,525	30,799	--------	720,584	--------	--------	--------	--------	--------	--------	--------
1922	29,458	71,842	777,287	--------	294,994	--------	--------	--------	--------	--------	--------	--------
1923	22,255	14,852	288,758	--------	162,772	--------	--------	--------	--------	--------	--------	--------
1924	22,045	19,037	589,513	--------	197,562	--------	--------	--------	--------	--------	--------	--------
1925	18,614	21,921	487,043	9	190,691	--------	--------	--------	--------	--------	--------	--------
1926	35,022	57,030	648,175	55	308,642	--------	--------	--------	--------	--------	--------	--------
1927	6,692	15,062	539,200	55	235,495	--------	--------	--------	--------	--------	--------	--------
Dead Bay: [1]												
1912	--------	5,400	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
1919	--------	--------	4,500	--------	--------	--------	--------	--------	--------	--------	--------	--------
1920	--------	--------	93,000	--------	--------	--------	--------	--------	--------	--------	--------	--------
1922	--------	35,000	20,000	--------	--------	--------	--------	--------	--------	--------	--------	--------
1924	2,000	24,724	293,381	--------	--------	--------	--------	--------	--------	--------	--------	--------
1925	1,142	23,484	377,783	--------	5,805	--------	--------	--------	--------	--------	--------	--------
1926	2,403	32,312	275,322	17	14,838	--------	--------	--------	--------	--------	--------	--------
1927	753	37,208	774,765	45	19,978	--------	--------	--------	--------	--------	--------	--------
Olga Bay:												
1889	--------	--------	--------	--------	343,005	--------	--------	--------	--------	--------	--------	--------
1890	--------	--------	--------	--------	443,911	--------	--------	--------	--------	--------	--------	--------
1891	--------	--------	--------	--------	345,800	--------	--------	--------	--------	--------	--------	--------
1892	--------	--------	--------	--------	274,001	--------	--------	--------	--------	--------	--------	--------
1893	--------	--------	--------	--------	335,101	--------	--------	--------	--------	--------	--------	--------
1894	--------	--------	--------	--------	360,360	--------	--------	--------	--------	--------	--------	--------
1895	8,321	--------	--------	--------	190,982	--------	--------	--------	--------	--------	--------	--------

See footnotes at end of table.

TABLE 7.—*Salmon catch and fishing appliances used in the Alitak Bay district, 1889 to 1927*—Con.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Olga Bay—Con.												
1896					[2] 277,860							
1897					[3] 513,000							
1898					[4] 409,184							
1899	2,024				380,798							
1900					395,446							
1901					540,982							
1902					586,989							
1903					356,188							
1904	2,200				730,733							
1905	1,863				213,080							
1906	1,242				364,958							
1907					707,562							
1908	3,896				218,033							
1909	460		112,169		308,784							
1910	3,327		38,187		174,450							
1911	1,440	6,492	201,809		495,496							
1912	2,452	2,772	33,871		284,314							
1913	3,901	3,822	198,111		208,497							
1914	5,164	9,520	183,030		139,241							
1915	10,841	8,420	100,403		255,368							
1916	227	10,030	83,308		465,805							
1917		2,000	2,300		532,118							
1918	6,794	25,655	478,623	73	228,250							
1919	4,994	7,322	1,200		72,144							
1920			32,000		88,409							
1921	3,216	3,964	2,500		245,612							
1922					52,890							
1923	5,565	4,951	762		3,173							
1924	7,964	3,814	8,590		41,197							
1925	693	6,488	5,630		3,275							
Portage Bay:												
1920			73,000									
1924		20,961	81,766									
1925	3,890	16,277	259,479		9,390							
1926	5	15,302	47,053		116							
1927	3,879	49,963	462,991	21	16,696							
Total:												
1889					343,605							
1890					443,911							
1891					345,800							
1892					274,001							
1893					335,101							
1894					360,360							
1895	8,321				190,982							
1896					[2] 277,860	5	1,000					
1897					[3] 513,000	5	1,000					
1898					[4] 409,184	5	1,000					
1899	2,024				380,798	6	1,200					1
1900					395,446	6	1,200					1
1901					540,982	8	1,600					1
1902					586,989	6	1,200					
1903					356,188	5	1,000					
1904	2,200				730,733	5	1,500			2	200	1
1905	1,863				213,080	5	1,500					
1906	1,242				364,958	6	1,800					
1907					707,562	5	1,500					
1908	3,896				218,033	5	1,500					
1909	460		112,169		308,784	4	1,200					1
1910	3,327		38,187		174,450	4	700					1
1911	1,440	6,492	201,809		495,496	4	960					1
1912	2,452	8,172	33,871		284,314	3	835					1
1913	3,901	3,822	198,111		208,497	4	1,090					
1914	9,164	12,520	273,030		229,241	4	615					1
1915	17,841	14,420	126,403		435,368	4	615					2
1916	824	14,628	155,572		723,315	6	1,570					2
1917	2,025	4,169	4,758		975,500	6	1,509					2
1918	24,222	42,282	1,020,789	820	569,602	10	1,695			1	100	6
1919	57,120	23,662	38,221		320,900	11	2,136			1	100	7
1920	47,287	40,349	712,262		485,356	10	1,638	2	550	2	150	10
1921	26,188	23,489	33,299		966,196	8	1,348	1	250			11
1922	29,458	106,842	797,287		347,884	9	1,400	2	500	4	600	11
1923	27,820	19,803	289,520		165,945	5	750					3
1924	32,009	68,536	973,250		238,759	7	1,050					7
1925	24,339	68,170	1,129,935	9	209,161	7	920					6
1926	37,430	104,644	977,550	72	323,596	8	970					5
1927	11,324	102,233	1,776,956	121	272,169	9	1,030					5

[1] Also known as Deadmans Bay. [2] Computed at 12 fish per case. [3] Computed at 13.7 fish per case.

[4] Included in this catch are 50,000 fish transferred to canneries at Uyak and 10,000 to Karluk canneries. The Olga Bay cannery also packed 60,000 red salmon from Red River (Ayakulik) and 35,000 from Chignik.

Almost if not quite the entire run of red salmon in this district is destined to the small streams of Olga Bay, although the table shows that between 1914 and 1924 there was a complete shift of fishing operations from Olga Bay to Alitak and Moser Bays; as the catches increased in Moser Bay there were corresponding decreases in the catches at the fishing grounds of Olga Bay. This shift in the fishing areas was accompanied by a shift in the type of gear used from seines to traps. The red salmon taken in Alitak and Moser Bays are undoubtedly Olga Bay fish, however, since the salmon entering Olga Bay must pass through Moser Bay, which is little more than a widening of the lower end of Olga Strait. It has been necessary for us to treat Moser and Alitak Bays as a single unit since in several years since 1914 the catches were reported as from "Alitak and Moser Bays," and it has been impossible to segregate the catches made in these two bays.

Alitak Bay is, however, the channel through which all salmon taken in Olga, Moser, Dead, and Portage Bays have approached their particular streams, so that a strict allocation of catch to the respective bays is not essential to a correct understanding of conditions in this district, at least in so far as the red salmon are concerned. Traps located on the east shore of Alitak Bay and traps set near the entrance of or between Dead Bay and Moser Bay take some red salmon. There are, however, no red salmon streams in Portage Bay or Dead Bay, and no red salmon were reported from either locality until 1925. There is no evidence that the red-salmon catch of this district draws upon other than the Olga Bay runs, nor is there evidence that this run is drawn upon by fisheries in other localities.[6]

Olga Bay has seven tributary streams which are used by salmon, but of these only four are recognized as red-salmon streams, and two of these are of little consequence. The important red-salmon streams are thus only two in number; one enters the bay from the north about midway between the east and west ends of the bay, and the other empties from the south near the west end of the bay. These streams are about 30 feet in width, 2 feet in depth, and flow at the rate of about 1½ miles an hour. The south stream is by far the more important; it is the outlet of two small lakes and several ponds; and upon its production of red salmon, the fishery largely depends. A comparison of these two streams shows the south stream produces six times as many red salmon as the north stream. Of the less important streams, the one at the east end of the bay known as Horse Marine has provided the greater number of reds in late years, whereas 30 years ago the one in the northwest section of the district at Silver Salmon Bay was the more productive.

Since 1924 the commercial catch of red salmon in the Alitak Bay district was restricted by the imposition of Federal regulations authorized under the act of Congress of June 6, 1924, providing that the escapement in streams where weirs are maintained for the purpose of counting salmon, shall equal the commercial catch. Weirs were first set across the north and south streams in 1923, and counts were made as shown in Table 8:

TABLE 8.—*Olga Bay red salmon runs from 1923 to 1927*

Year	North Stream	South Stream	Total known escapement	Commercial catch	Total known run
1923	15, 855	167, 775	183, 630	165, 945	349, 575
1924	19, 867	302, 008	321, 875	238, 759	560, 634
1925	40, 910	509, 700	550, 610	209, 161	759, 771
1926	105, 142	789, 947	895, 089	323, 596	1, 218, 685
1927	87, 949	497, 619	585, 568	272, 169	857, 737

In addition to the foregoing, there was an estimated escapement of 25,000 reds into Horse Marine stream in 1926, while a similar estimate in 1927 gives that stream an escapement of 30,000 and at Silver Salmon Bay, 5,000; thus bringing the total escapement for the respective years to 920,089 and 620,568, and the total known run of reds to 1,243,685 in 1926 and 892,737 in 1927.

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[6] It has been noted in the past year or two, however, that many of the fish passing through the weirs in this district bear the marks of gill nets. Just where the Olga Bay fish pass through a gill-net fishery is not definitely known but it seems probable that it is along the northwest coast of Kodiak Island.

The general trend of the red-salmon catch at Alitak is shown in Figure 5 and was determined by a moving average by fives. It is seen that the catches were above average for a considerable period between 1895 and 1908, were relatively low from 1908 to 1915, and then were high again until about 1923. Beginning with 1924 the catches have been materially affected by the regulations and the records can not be considered as comparable with those of earlier years. Extraordinary catches were made in both 1917 and 1921—catches that were considerably higher than any recorded before or since. So far as we can determine there was no material change in the intensity of fishing during this period, and it seems safe to conclude that the runs were unusually large in these years. The fluctuations of the trend, or long-time movement, do not clearly indicate depletion although the reduced catches in recent years may be due in part to this condition. It can not be said, however, that there are definite evidences of depletion shown by these data since the shift in the nature of the fishery that has occurred since 1914 may have obscured any change in general abundance that has taken place.

The cyclical or short-time changes are very irregular at Alitak as is shown by Figure 6, which shows the yearly fluctuations about the trend as a percentage of the trend. The coefficients of correlation in the cyclical fluctuations at 4 and 5 year intervals have been calculated and found to be statistically insignificant. (See Part I, p. 62, for a discussion of this procedure.) Inspection of the data showed also that there was no significant correlation at 6-year intervals, although the coefficient was not calculated. The value of "r" for the 4-year interval was +0.247 ±0.119, and for the 5-year interval +0.204 ±0.124. It is evident that there are no clear-cut cycles of abundance in the Alitak red salmon such as have been demonstrated for the Bristol Bay and Karluk fish. This is presumably due, as at Chignik, to the fact that the fish are not so predominantly of a single age group. Observations made by the late Dr. C. H. Gilbert showed wide fluctuations in the abundance of different age groups at different times during the season of 1914. The predominant age during the latter part of the season was 5 years, but earlier in the season 6-year and even 7-year fish were very common. Since these observations cover only the one year, and that some time ago, they can not be considered as certainly typical of the runs of this district, but the presence of relatively large percentages of at least two age groups indicates that this condition may be the cause of the lack of correlation in the catches at definite intervals.

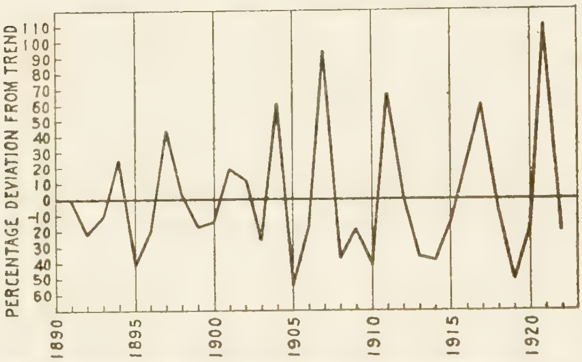

FIGURE 6.—Percentage fluctuation from the trend of the catch of red salmon at Alitak

OTHER SPECIES

Previous to 1909 the catch of species other than reds was confined to occasional years in which a few cohos were taken. Beginning in 1909 and continuing through 1927, catches of coho, chum, and pink salmon, particularly the latter, were regularly made in this district. In recent years, however, the greater part of the catch of these species has come from Alitak, Portage, and Dead Bays, with comparatively small catches in Olga Bay except in 1918 when over half a million were reported. The data are presented graphically in Tables 9, 10, and 11.

As pointed out elsewhere in this review, a peculiar situation exists at Alitak in respect to abundance and scarcity of pink salmon. At the beginning of fishing for pink salmon in 1909, the heavier runs occurred in the odd years, but from 1914 to 1924, inclusive, the even years were by far the most productive. In 1925, the heavy runs swung back to the odd years, the catch in both that year and 1927 exceeding 1,000,000. The highest level of production was reached in 1927 with a catch of 1,776,956, which may be regarded as evidence of an increasing supply of pinks in this district as there is no evidence that fishing was more intense. No information is available whereby an approximation of the escapement of pinks can be shown. Relatively small numbers were counted through the weirs maintained in two red-salmon streams, yet the run seems to be entirely local, and not, as in some other Kodiak Island localities, a body of migrating salmon.

TABLE 9.—*Graphic table of catches of pink salmon in Alitak district*

[Each letter in this table represents 50,000 fish. The letter "A" indicates the catch in Alitak and Moser Bays; "Q" the catch in Dead Bay; "O" the catch in Olga Bay; and "V" the catch in Portage Bay]

Year	Catch
1909	OOO
1910	O
1911	OOOOO
1912	O
1913	OOOO
1914	OOOOAA
1915	OOOA
1916	OOAA
1917	OA
1918	OOOOOOOOOOAAAAAAAAAAA
1919	OAQ
1920	OAAAAAAAAAAQQVV
1921	OA
1922	AAAAAAAAAAAAAAAAQ
1923	OAAAAAA
1924	OAAAAAAAAAAAAQQQQQQVV
1925	OAAAAAAAAAAQQQQQQQQVVVVVV
1926	AAAAAAAAAAAAAQQQQQQV
1927	AAAAAAAAAAAQQQQQQQQQQQQQQQQVVVVVVVVVV

TABLE 10.—*Graphic table of catches of cohos in Alitak district*

[Each letter in this table represents 2,000 fish. See Table 9 for explanation of letters]

Year	Catch
1909	O
1910	OO
1911	O
1912	OO
1913	OO
1914	OOOAA
1915	OOOOOOAAAA
1916	OA
1917	AA
1918	OOOOAAAAAAAAA
1919	OOOAAAAAAAAAAAAAAAAAAAAAAAAAAA
1920	AAAAAAAAAAAAAAAAAAAAAAAA
1921	OOAAAAAAAAAAAA
1922	AAAAAAAAAAAAAAA
1923	OOOAAAAAAAAAAAA
1924	OOOOAAAAAAAAAAAAQ
1925	OAAAAAAAAAAQVV
1926	AAAAAAAAAAAAAAAAAAQQV
1927	AAAAQVV

Table 11.—*Graphic table of catches of chum salmon in Alitak district*

[Each letter in this table represents 5,000 fish. See Table 9 for explanation of letters]

Year	Catch
1911	OO
1912	OQQ
1913	O
1914	OOA
1915	OOAA.
1916	OOOA
1917	OA
1918	OOOOOOAAAA
1919	OOAAAA
1920	AAAAAAAAA
1921	OAAAA
1922	AAAAAAAAAAAAAAAQQQQQQQQ
1923	OAAA
1924	OAAAAQQQQQVVVVV
1925	OOAAAAAQQQQQVVVV
1926	AAAAAAAAAAAAQQQQQQQVVVV
1927	AAAQQQQQQQQQVVVVVVVVVV

The presence of pink salmon in these waters in such unusual and increasing numbers may reasonably cause speculation as to the failure to utilize them in any considerable quantities before 1918. Since exactly the same situation obtains in respect to cohos and chums, it would appear that no effort was made to take these cheaper grades of salmon until the new cannery was opened in that year. The shift of the fishery from Olga Bay to the outer bays and from a seine to a trap fishery may have been the chief cause of the increased catches.

The catches of cohos and chums show no special features other than the increased catch in the years since 1918, which was mentioned above. King salmon were reported in only four years. The first catch was made in 1918 when 820 were taken. No more kings were reported until 1925, and since then the yearly catches range from 9 to 123. This species has evidently no real economic importance.

RED RIVER DISTRICT

The Red River district is composed of the coastal waters of Kodiak Island from Cape Karluk on the north to Cape Alitak on the south, and it embraces but few salmon streams, of which Red River is the only important one. At one time there was some fishing at a stream near Low Cape, but the catches there were insignificant and were reported as Red River fish. Sturgeon River near the northern end of the district produced a few cohos in two widely separated years and in 1920 a small catch of pinks was made. Red River is properly known as Ayakulik River and is so referred to in the reports by Moser who says: "Among cannery men it is known as Red River, but this name should not be confounded with the Red River which lies 6 miles to the northward according to Coast Survey chart No. 8500" (Moser, 1902). On account of the present universal use, the name "Red River" has been adopted for this stream.

The data for this district are given in Table 12.

TABLE 12.—*Salmon catch and fishing appliances used in the Red River district, 1896 to 1922*

Year	Coho	Chum	Pink	King	Red	Beach Seines	
						Number	*Fathoms*
Red River:							
1896					42,000		
1898					60,000		
1900					285,000		
1901[1]					200,000		
1902[1]					200,000		
1903[1]					100,000		
1904					167,175	7	
1905					58,805	7	
1906					163,465	10	
1907					312,377	10	3,000
1908			17,381		286,112	4	2,000
1909					201,007	4	1,600
1910			16,317		99,308	4	2,000
1911					176,788	4	1,800
1912		1,495	67,523		412,907	4	1,600
1913			615		293,439	4	1,600
1914			42,188		142,657	4	1,600
1915				15	212,124	4	1,600
1916		124	22,210		215,142	3	1,500
1917		33	49		222,376	3	1,500
1918		942	167,914	152	147,191	3	1,500
1919		75	27	364	80,375	3	750
1920		23	52,006	66	14,632	4	1,200
1921					28,977		
1922			26,862		12,222		
Sturgeon River:							
1910	5,000						
1920			7,138				
1922	4,000						

[1] Catches estimated.

NOTE.—The catch of red salmon at Red River in 1901, 1902, and 1903 was estimated and deducted from the reported catch at Karluk, as there was no allocation to Red River in those years. No catch was reported in the years not shown in this table.

Little is known of the early history of salmon fishing at Red River, but available records indicate that operations began soon after the establishment of canneries at Karluk and Olga Bay. These meager records give in general the impression that a considerable run of red and humpback salmon came to this stream, and that such catches as were made there formed appreciable parts of the packs at near-by canneries. The first authentic record of a catch of salmon at Red River, however, was made by the Alaska Improvement Co. in 1896 when 42,000 reds were taken at that fishery and packed at Karluk; yet it is a generally accepted fact that commercial fishing had been carried on annually for several years prior thereto. Stream statistics were not kept for publication in those years, as the item of chief interest was the number of cases packed regardless of the source of the salmon procured. Usually the pack of any cannery was allocated, if at all, to the important stream nearest the location of the plant, so in that way the catches at Red River in several seasons were lost in combination with catches at Karluk, Olga Bay, Uganik, and probably Chignik. In 1902, Moser[7] reported that the catch of red salmon off the mouth of Red River in 1900 was estimated at 700,000 and that early in August pink salmon schooled in such numbers at the mouth of the river as to stop fishing for reds since pinks were then regarded as almost worthless. If this figure is even approximately correct, a large part of the catch is unaccounted for inasmuch as the detailed catch statistics given also by Moser show only that 285,000 red salmon were taken that year, of which 25,000 were packed at Alitak, 242,500 at Karluk, and 17,500 at Uganik. There is no way of knowing which of these estimates is nearest the truth but the smaller figure has been adopted since the larger one is greatly in excess of the maximum catch reported in any other year.

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[7] Alaska Salmon Investigations in 1900 and 1901, by Jefferson F. Moser. Bulletin, U. S. Fish Commission, 1901 (1902), Vol. XXI, pp. 173–401. Washington.

In 1897, no catch was reported, while in 1898 Red River produced apparently only 60,000 red salmon, all of which were canned at Alitak. There are also no records of catches in 1901, 1902, or 1903, although it may be accepted as indisputably true that once a fishery was established at Red River it was continued each year until 1922, even to the almost total extinction of the run, and was then stopped by Federal regulation.

Beginning in 1904 and thereafter through 1922, catch statistics were taken from the sworn reports of operators at Red River, though in some of these years the figures may not tell the whole story. It is likely that in the earlier years of this period, part of the salmon taken here were credited elsewhere, probably Karluk. After the elimination of all but two packing companies operating on the west coast of Kodiak Island (the Alaska Packers Association and the Northwestern Fisheries Co.) it would appear that the reported catch of salmon at Red River might be accepted without question. Yet an examination of these records reveals that the only salmon taken at that fishery in 1904, 1905, and 1907, were reported by the Northwestern Fisheries Co. In the period from 1908 to 1914, both companies fished there except in 1911 when the Alaska Packers Association confined its fishing to Karluk Beach, Uganik Bay, and Little River. From 1914 to 1921, inclusive, the entire catch of salmon at Red River went to the Uyak Bay cannery of the Northwestern Fisheries Co., so that there should be no confusion of figures for that period. The rather insignificant catch of 1922 was made by three companies which had not previously fished in that locality.

Red River is the only salmon stream of any importance in the southwest section of Kodiak Island between Karluk and Alitak Bay. It is a comparatively small stream, only about 50 feet in width, and rises in a lake and tributaries about 15 miles inland beyond the glacial moraine through which it flows to the ocean, debouching on a bold shore midway between Cape Ikolik and Low Cape. Between these points the coast is exposed to the full sweep of wind and sea from a southwesterly direction so that fishing is frequently interrupted for periods of varying length by storms from that quarter. Perhaps no season in all the history of the fishery has been without these interruptions, which in themselves should be regarded as favorable to the escapement of salmon into the stream, yet only one other known stream on Kodiak Island shows equally serious depletion of its salmon run, almost to the point of complete destruction. Considering also that Red River was strictly a beach-seine fishery, with more than average natural protection, it seems almost incredible that a substantial run should not have been stabilized in the stream. This is especially true in view of the fact that throughout the entire history of the fishery, from 1904 until 1922, operations were carried on by not more than two companies, and after 1914 by only one, and without that destructive competition which marked operations at many other localities in Alaska. In the same period no restrictive regulations were enforced other than those imposed by the act of June 26, 1906, which provided a weekly closed period of 36 hours and prohibited fishing within 100 yards outside of the mouth of all streams less than 500 feet in width.

Assuming that the law was obeyed, no satisfactory explanation of the depletion of the red salmon run to this stream can be given; but the conclusion may be reached safely that with such small streams, even favorable natural conditions for the preservation of a salmon run are inadequate unless supplemented by the enforcement of legal protection. Modern fishing methods and practices are capable of destroying a commercial run of salmon in any stream if allowed unrestricted employment, and the smaller the stream the more readily may this be done. There seems to be no good reason why Red River can not support a run of red salmon capable of yielding between 100,000 and 150,000 fish annually for commercial use. Table 13 shows graphically a wide fluctuation in the catch of red salmon and that the maximum yield was reached in 1912 when 412,907 were taken. In 1913 the catch dropped to 293,439 and in 1914 further declined to 142,657. It increased to 212,124 in 1915, and remained slightly above that level for two years following. In 1918, the catch again dropped to 147,191, and another sharp drop in 1919 brought the catch down to 80,375. A still more serious decline occurred in 1920 when the catch fell to 14,632. The slight recovery in 1921 brought the catch only to 28,977, and this was followed in 1922 by a catch of 12,222, the lowest figure it had reached in 19 years. Since that year, commercial fishing for salmon at Red River has been prohibited. Occasional observations of the spawning grounds in Red River have been made in recent years and in 1929 a counting weir was established and an escapement of 28,980 fish recorded. This represents, no doubt, the entire run and is so far below the former productivity of the stream as measured by the catch records alone that excessive depletion is clearly indicated. The earlier reports of observations made on the spawning grounds were much more favorable than this weir count indicates, and a continuation of the weir count will be watched with great interest. We have here an opportunity to observe the natural increase of a very seriously depleted run and the results will be of great importance from both practical and scientific points of view.

TABLE 13.—*Graphic table of catches of red salmon at Red River*

[Each letter in this table represents a catch of 10,000 fish]

Year	Catch
1904	RRRRRRRRRRRRRRRRR
1905	RRRRRR
1906	RRRRRRRRRRRRRRRRR
1907	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1908	RRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1909	RRRRRRRRRRRRRRRRRRRR
1910	RRRRRRRRRR
1911	RRRRRRRRRRRRRRRRRR
1912	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1913	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1914	RRRRRRRRRRRRRRRR
1915	RRRRRRRRRRRRRRRRRRRRRR
1916	RRRRRRRRRRRRRRRRRRRRRR
1917	RRRRRRRRRRRRRRRRRRRRRRR
1918	RRRRRRRRRRRRRRR
1919	RRRRRRRRR
1920	RR
1921	RRR
1922	RR

The Red River fishery has produced rather limited quantities of pink salmon in each of the even years from 1908 to 1922, but these catches were wholly incidental to fishing for red salmon. Pinks were obtainable in large numbers in some seasons. Moser points out that in 1900 they schooled in dense masses off the mouth of the river early in August and put an end to fishing for red salmon before the usual closing of the season for that species. Available statistics give no indication of the size of pink salmon runs to Red River; likewise there is no information to show that king and chum salmon are taken except in very limited quantities. Cohos have not been reported from this locality at any time.

Fishing gear credited to this district was operated by the Northwestern Fisheries Co., as a part of its Karluk equipment. A division was made whereby the Red River fishery is credited with about half of the gear used by this company, but no gear of the Alaska Packers Association was allocated to this district, although the association fished here a few seasons. Neither company reported separately the gear used at Red River.

KARLUK RIVER DISTRICT

This district embraces a small section of the west coast of Kodiak Island in which the seining grounds at the mouth of Karluk River and those adjacent at Slide, Waterfall, and Tanglefoot, constitute one of the most compact fishing areas in all Alaska. Karluk River, a fine clear-water stream, is the outlet of Karluk Lake and the streams of its drainage basin, and is approximately 30 miles in length. It empties into a lagoon or estuary formed by the action of surf and tide which have thrown a high sand and gravel spit across the mouth of the river. This lagoon is about 3 miles long, and in the early days was the preferred seining ground, as operations could be carried on there without interruption by storms and heavy surf.

Although other species are taken in the fishery the remarkable red-salmon runs are of predominant importance. Both the river and the lake are relatively small, yet the abundance of red salmon is so great as to indicate that conditions are particularly favorable for this species. No other stream of similar size is known to produce such large runs, and there are only a few larger streams, such as the Fraser and the Kvichak Rivers, that have been more productive. Occasionally large runs of pinks have appeared and the three other species are taken in significant though much smaller numbers.

In the eighteenth century, Russian explorers discovered and reported great runs of salmon at Karluk, and the Indians, of course, knew of them long before the Russians came. It is a matter of record that 300,000 red salmon were prepared as "yukola" (dried without salting or smoking) in several seasons more than a century ago.[8] Yet no commercial use seems to have been made of the Karluk salmon until after Alaska was purchased by the United States in 1867. The first cannery was built on Karluk Spit in 1882, and for six seasons this one plant operated without competition. The catches increased from 58,800 in 1882 to 1,004,500 in 1887, each intervening year showing a material gain over the preceding. It seems very probable that every salmon captured in these six years was taken in Karluk Lagoon, as fishing on the outside beaches was not engaged in until the competition incident to the establishment of more canneries forced such action.

In 1888, the number of canneries increased to 4, of which 3 were located at Karluk and 1 at Larsen Bay, and the catch amounted to approximately 2,781,000. In the next year, 2 additional canneries were opened and the combined catch of the 6 plants was 3,412,000, no part of which is presumed to have been made elsewhere than at Karluk River. In 1890, the catch was 3,149,000, without change in the number of canneries. The catch in 1891 was 3,500,000, with 6 canneries still in operation. From 1892 to 1895, a period of four years, the number of canneries varied from 3 to 5, and the catch varied from 2,056,000 in 1895 to 3,350,000 in 1894. In all these years no record was made of the number of salmon caught, but the catch has been computed from the reported pack in each year at the rate of 14 fish per case.

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[8] Sketches from History of American Orthodox Ecclesiastical Mission, Kodiak Mission, 1837-1894. Published by Monastery of Valaam, St. Petersburg, 1894. Translation by N. Gray, Kodiak, Alaska, 1925.

According to Moser[9] this was the number of Karluk red salmon required to pack a case in 1895 and all earlier years, and it is still about the same. In 1896, for reasons unknown, Moser computed the catch at 12 fish per case, and thus obtained a catch of 2,483,976, in addition to which 155,000 reds were transferred to canneries at Chignik. For the first time salmon were reported from Uganik, "Ayagulik" (probably intended for Ayakulik or Red River), Kaguayak, and Little River, but the estimated catches at these places were excluded from the Karluk catch. It is believed, however, that in several years before and after 1896, Karluk catch statistics were slightly in error due to the inclusion of fish taken at other localities, but no attempt has been made to correct this, except as indicated in the footnotes following Table 14. Catches by species were reported for the first time in 1897. No allocation to streams other than Karluk River was shown, although one company listed Little River, Uganik, Red River, and "Ayagulik" besides Karluk, but the catch at each place was not shown separately. In this year, Kutchin[10] reports that the catch of red salmon by the three canneries at Karluk and one at Uganik was 1,865,731. The Uganik cannery packed 2,113 cases. The Uganik fish are much larger than those at Karluk, running about 10 to the case. It is assumed, therefore, that approximately 21,000 reds were caught in Uganik Bay, and the Karluk catch as given by Kutchin has been reduced by that number. The first catch of cohos ever reported from Karluk was also made in that year. From 1897 to 1903, both years inclusive, Kutchin's catch statistics have been used and wherever salmon from other designated localities were included as Karluk fish, adjustment has been made by allocating a part of the catch to those streams. Such allocations have been based on a knowledge of local conditions, and while they are open to criticism on that account they are believed to be reasonably accurate.

Beginning in 1904 and continuing through 1927, data were obtained from statistical reports of the operators filed in Washington. In this period, then, serious error in catch statistics, while not entirely removed, is decidedly improbable. The history of this district is particularly interesting, and marks the rise and fall of one of the world's greatest red-salmon fisheries.

The data are presented in Table 14.

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[9] The Salmon and the Salmon Fisheries of Alaska, by Jefferson F. Moser. Bulletin of the U. S. Fish Commission for 1898, Vol. XVIII, pp. 1-178. Washington, 1899.

[10] Report on the Salmon Fisheries of Alaska, 1897, by Howard M. Kutchin. Treasury Department, Document No. 2010, division of special agents, Washington, 1898.

TABLE 14.—*Salmon catch and fishing appliances used in the Karluk River distriict, 1882 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Gill nets	
						No.	*Fathoms*	*No.*	*Fathoms*
1882	----	----	----	----	58, 800	----	----	----	----
1883	----	----	----	----	188, 706	----	----	----	----
1884	----	----	----	----	282, 184	----	----	----	----
1885	----	----	----	----	468, 580	----	----	----	----
1886	----	----	----	----	646, 100	----	----	----	----
1887	----	----	----	----	1, 004, 500	----	----	----	----
1888	----	----	----	----	2, 781, 100	----	----	----	----
1889	----	----	----	----	3, 411, 730	----	----	----	----
1890	----	----	----	----	3, 148, 796	----	----	----	----
1891	----	----	----	----	3, 500, 588	----	----	----	----
1892	----	----	----	----	2, 852, 458	----	----	----	----
1893	----	----	----	----	2, 909, 508	----	----	----	----
1894	----	----	----	----	3, 349, 976	----	----	----	----
1895	----	----	----	----	2, 055, 984	----	----	----	----
1896	----	----	----	----	2, 638, 976	15	6, 475	----	----
1897	1, 500	----	----	----	[1] 2, 204, 425	29	9, 375	3	600
1898	19, 175	----	----	----	[2] 1, 534, 064	29	9, 800	----	----
1899	30, 451	----	----	1, 104	[3] 1, 399, 117	29	9, 950	----	----
1900	32, 239	----	----	4, 838	[4] 2, 594, 774	31	10, 450	----	----
1901	----	----	2, 015	3, 838	[5] 3, 985, 177	41	16, 400	2	200
1902	34, 972	----	----	2, 932	[5] 2, 981, 112	18	7, 200	----	----
1903	119, 541	----	10, 000	1, 187	[6] 1, 319, 975	18	7, 200	----	----
1904	100, 936	----	5, 180	3, 190	1, 638, 949	17	----	----	----
1905	85, 050	----	----	2, 496	1, 787, 642	20	----	----	----
1906	22, 496	----	----	3, 640	3, 382, 913	20	----	----	----
1907	26, 033	----	----	4, 015	2, 929, 886	20	3, 000	----	----
1908	33, 131	----	233, 067	3, 028	1, 608, 418	5	3, 900	----	----
1909	13, 655	----	----	3, 907	923, 501	11	3, 600	----	----
1910	22, 922	----	104, 873	1, 598	1, 492, 544	13	5, 680	----	----
1911	11, 581	----	8, 742	689	1, 723, 132	10	4, 350	----	----
1912	10, 466	14, 921	287, 890	686	1, 245, 275	14	6, 105	----	----
1913	16, 175	----	11, 892	1, 032	868, 422	15	6, 455	----	----
1914	16, 048	----	1, 287, 190	886	540, 455	16	6, 415	----	----
1915	20, 173	5, 048	12, 758	777	828, 429	8	3, 087	----	----
1916	20, 389	11, 823	2, 492, 552	564	2, 343, 104	8	3, 478	----	----
1917	21, 620	4, 878	752	750	2, 324, 492	8	3, 477	----	----
1918	45, 220	12, 569	335, 988	890	1, 094, 665	8	3, 429	----	----
1919	35, 305	12, 360	5, 621	784	1, 089, 809	11	3, 486	----	----
1920	26, 924	5, 499	634, 977	1, 571	1, 368, 526	11	3, 631	----	----
1921	13, 440	87	38	638	1, 631, 247	10	3, 595	----	----
1922	21, 604	10, 369	894, 175	661	656, 092	10	3, 745	----	----
1923	20, 029	4, 007	9, 883	1, 776	662, 140	8	3, 151	----	----
1924	10, 775	2, 318	2, 442, 359	294	742, 489	10	3, 630	----	----
1925	4, 750	1, 582	6, 265	1, 077	1, 136, 508	8	2, 935	----	----
1926	14, 013	17, 065	86, 040	88	1, 825, 486	8	3, 050	----	----
1927	14, 344	6, 538	2, 537	1, 383	398, 726	5	1, 780	----	----

[1] Used Kutchin's report of catch, and deducted 21,130 reds as Uganik catch.
[2] Does not include 50,000 reds transferred from Olga Bay to Uyak and 10,000 to Karluk.
[3] Does not include 15,000 reds transferred from Olga Bay to Uyak.
[4] Does not include 242,500 reds transferred from Red River and 24,000 from Uganik.
[5] Does not include 200,000 estimated catch of reds at Red River and 100,000 at Uganik.
[6] Does not include 100,000 estimated catch of reds at Red River and 50,000 at Uganik.

NOTE.—This table includes all salmon caught at Slide and Waterfall. The number of fathoms of seines used in 1901, 1902, and 1903 was estimated at 400 per seine. The gill nets used in 1901 were estimated to total 200 fathoms.

RED SALMON

Many investigations of the Karluk red-salmon fishery have been made, much has been written about it, commercial interests have battled for exclusive control and domination of it, and dire prophecies have been heard concerning its ultimate destruction. Because of these things, Karluk has undoubtedly been given more close attention than any other fishery in Alaska. Approximately 10 years ago the late Dr. C. H. Gilbert undertook a detailed study of the Karluk red-salmon runs. The senior author of this paper was associated with him in this investigation from 1926 on. One paper dealing with these investigations has been published.[11] In this report statistics were given of the catch of red salmon at Karluk from 1882 to 1926, but these data do not always agree with those presented herewith which have been derived more from original sources and are, without doubt, more reliable. For a number of the years previous to 1904 the figures given here are higher than those given by Gilbert and Rich.

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[11] Investigations Concerning the Red-Salmon Runs to the Karluk River, Alaska, by Charles H. Gilbert and Willis H. Rich. Bulletin of the Bureau of Fisheries, Vol. XLIII, 1927, Part II. Washington, 1927.

This is due chiefly to our inclusion of packs made by canneries at Larsen and Uyak Bays, which were not included in the figures of Gilbert and Rich. In 1896 Moser estimated the catch on the basis of 12 fish per case, but in this report 14 has been used as being much more nearly correct for Karluk red salmon. Bureau figures checked closely with those of Gilbert and Rich for the years 1904 to 1924.

TABLE 15.—*Graphic table showing catch of red salmon at Karluk, 1882–1927*

[Each letter indicates 100,000 fish]

Year	Catch
1882	X
1883	XX
1884	XXX
1885	XXXXX
1886	XXXXXXX
1887	XXXXXXXXXXX
1888	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
1889	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1890	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1891	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1892	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1893	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1894	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1895	XXXXXXXXXXXXXXXXXXXXX
1896	XXXXXXXXXXXXXXXXXXXXXXXXXXX
1897	XXXXXXXXXXXXXXXXXXXXXXX
1898	XXXXXXXXXXXXXXXX
1899	XXXXXXXXXXXXXX
1900	XXXXXXXXXXXXXXXXXXXXXXXXXX
1901	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1902	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1903	XXXXXXXXXXXXXX
1904	XXXXXXXXXXXXXXXXX
1905	XXXXXXXXXXXXXXXXXX
1906	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1907	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1908	XXXXXXXXXXXXXXXXX
1909	XXXXXXXXXX
1910	XXXXXXXXXXXXXXX
1911	XXXXXXXXXXXXXXXXXX
1912	XXXXXXXXXXXXX
1913	XXXXXXXXX
1914	XXXXXX
1915	XXXXXXXXX
1916	XXXXXXXXXXXXXXXXXXXXXXXX
1917	XXXXXXXXXXXXXXXXXXXXXXXX
1918	XXXXXXXXXXX
1919	XXXXXXXXXXX
1920	XXXXXXXXXXXXXX
1921	XXXXXXXXXXXXXXXXX
1922	XXXXXXX
1923	XXXXXXX
1924	XXXXXXXX
1925	XXXXXXXXXXXX
1926	XXXXXXXXXXXXXXXXXXX
1927	XXXX

Beginning in 1924, with the introduction of traps on the northwest coast of Kodiak Island, our figures do not agree with those published by Gilbert and Rich, and by Bower,[12] but represent catches made only in the Karluk district, which lies entirely between Cape Karluk and Cape Uyak. (See Table 15.) Previously published reports of the commercial catch of Karluk salmon from 1924 to 1927 include reds caught several miles north of Karluk and differ from our data in the following particulars: In 1924 the catch was reported as 890,752, or approximately 20 per cent more than our total for that year; in 1925 it was given as 1,317,742, or nearly 16 per cent above the total compiled by the authors; in 1926 it was 2,131,616, or about 17 per cent in excess of figures for the same year; in 1927 it was 600,778, or approximately

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[12] Alaska Fishery and Fur-seal Industries in 1924, by Ward T. Bower. Appendix IV, Report, United States Commissioner of Fisheries for 1925, p. 114. Appendix III, Report, United States Commissioner of Fisheries for 1926, p. 100. Appendix IV, Report, United States Commissioner of Fisheries for 1927, p. 266. Appendix IV, Report, United States Commissioner of Fisheries for 1928, p. 101. Washington.

51 per cent above our total. As already noted, the interception of the Karluk run in these years was due largely to the operation of traps near the entrance of the bays between Outlet Cape and Karluk, and the increase in the number of salmon intercepted is in direct relation to the number of traps employed. Fishing appliances on that coast north of Cape Uyak in 1924, 1925, and 1926 took 1 fish out of the Karluk red-salmon run, as against 5 taken by seines on the Karluk beaches, whereas in 1927 with a considerable increase in the number of traps and nets 1 Karluk salmon was taken in that same area in comparison with 2 taken in beach seining at the river.

It is apparent that the development of the fishery to the north and east of Karluk River is taking an increasing percentage of the total catch of Karluk reds. Bower gives the total catch of Karluk red salmon in 1927 as 600,778 while our figures show that only 398,726 were taken at Karluk beach. Over a third, then, of the total catch was made at other points and it may be expected that further expansion along this line will make deeper inroads into the Karluk run and reduce the catch correspondingly at the river, while the burden of conservation will fall heaviest upon operations nearest the streams.

This change in the proportion of the run caught in these two localities furthermore shows conclusively that a large part of the Karluk run comes from the north and closely follows the coast of Kodiak Island. It is not known to what extent it comes, if at all, through Kupreanof Strait or around the north end of Afognak and Shuyak Islands, for there is the possibility that the runs come in from the south and west, taking a mid-channel course and are not dispersed toward the Kodiak shore until after reaching the point in Shelikof Strait where the tides meet and cause a southward current to set along the northwest coast of Kodiak Island.

It is definitely known that the fish taken in this part of the northwestern coast of Kodiak Island are derived largely from the Karluk River runs and should, therefore, properly be included in any complete consideration of the Karluk red-salmon runs. This was conclusively shown by tagging experiments conducted in Uganik Bay in 1927.[13] No attempt has been made here, however, to consider the Karluk red-salmon run in this manner and Table 15 presents solely the catch made at the Karluk beach.

It does not seem desirable in this report to consider in detail the many interesting and significant facts that appear in the history of the Karluk red-salmon fishery. These have been discussed in the report of Gilbert and Rich, to which the reader is referred, and will be given further consideration in connection with the future intensive investigations that are being carried on. The modifications in our data are not great enough to seriously change the conclusions reached by Gilbert and Rich; in fact they make still more apparent the fact that this run has been greatly depleted. The picture presented by Table 13 is one of gradual reduction from the early period of high productivity to a level approximately half that maintained from 1888 to 1902. Until very recently there had been no material change in the laws and regulations to affect the fishing effort yet the good years were becoming less productive and the poor years were yielding constantly smaller catches. Catches in the four years from 1924 to 1927, however, were curtailed by the enforcement of a provision of the law of 1924 that wherever a weir was maintained in a salmon stream for the purpose of counting the salmon ascending to the spawning grounds, the escapement shall not be less than 50 per cent of the run. Even before this law was enacted counts of salmon escaping into Karluk River were made. Counting began in 1921 and has been carried on each year since. Table 16 shows the commercial catch, known escapement, and known run as determined by a combination of catch and escapement. The catch here considered includes only that made at Karluk beach.

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[13] Salmon-Tagging Experiments in Alaska, 1927 and 1928, by Willis H. Rich and Frederick G. Morton. Bulletin U. S. Bureau of Fisheries, Vol. XLV, 1929, Document No. 1057.

TABLE 16.—*Catch and escapement of red salmon at Karluk from 1921 to 1927*

Year	Commercial catch	Known escapement	Total known run
1921	1, 631, 247	1, 325, 654	2, 956, 901
1922	656, 092	384, 683	1, 040, 775
1923	662, 140	694, 579	1, 356, 719
1924	742, 489	775, 705	1, 518, 194
1925	1, 136, 508	1, 620, 927	2, 757, 435
1926	1, 825, 486	2, 533, 412	4, 358, 898
1927	398, 726	872, 538	1, 271, 264

OTHER SPECIES

King salmon have been taken at Karluk in every year since 1898; but since 1910 the catch has been small, falling below 1,000 in 12 seasons. The largest catch of kings at Karluk occurred in 1900 when 4,838 were taken, the smallest in 1926 when only 88 were caught. The catch statistics as shown in Table 14 indicate that the run of kings is unimportant, but by taking into consideration the number passing through the weir each season since 1921, it will be observed that the run attained significant proportions, as shown by Table 17.

TABLE 17.—*Karluk king salmon catch, 1922 to 1927*[1]

Year	Catch	Escapement	Total	Percentage of run caught	Per cent-age of run escaping
1922	661	9, 572	10, 233	6. 27	93. 73
1923	1, 776	14, 442	16, 218	10. 95	89. 05
1924	294				
1925	1, 077	13, 379	14, 456	7. 45	92. 55
1926	88	5, 917	6, 005	1. 47	98. 53
1927	1, 383	10, 343	11, 726	11. 80	88. 20

[1] No count was reported in 1924.

Kings run at Karluk early in the season and, presumably, mingle freely with the red salmon. They are caught in seines operated on the Karluk beaches just as all other salmon are taken at that fishery, yet the average escapement in each of the five years shown in Table 17 was approximately 90 per cent of the run. No explanation of this surprising situation is known. There would seem to be no reason why the present catch of this species should be materially lower than in the years preceding 1910.

Cohos were first reported from Karluk in 1897. It is not improbable that they were taken at a much earlier date but were not utilized, or were not reported separately until several years after the industry was well established there. After the peak production of 1903, 1904, and 1905, when approximately 100,000 were taken each year, the catch dropped to an average yield of about 20,000 for the last 20 years. The catch from 1906 to 1927 was remarkably uniform, there being only one exceptionally good year and one abnormally poor year in that period. There is no distinctive coho fishery at Karluk, the entire catch of cohos being strictly incidental to fishing for red salmon. It is probable that the cohos run more abundantly after the cessation of fishing at the close of the red-salmon season, so that the commercial catch as given in Table 14 forms a relatively small percentage of the total run. At any rate, the catch gives little indication of the size of the run, a fact amply demonstrated by the count of cohos through the Karluk River weir from 1923 to 1927 as shown in Table 18.

TABLE 18.—*Karluk coho salmon run, 1923 to 1927*

Year	Catch	Escapement	Total	Percentage of run caught	Percentage of run escaping
1923	20,029	34,337	54,366	36.84	63.16
1924	10,775	(1)	-----	-----	-----
1925	4,750	15,445	20,195	23.52	76.48
1926	14,013	18,254	32,267	43.43	56.57
1927	14,344	18,281	32,625	43.97	56.03

[1] No count made. Weir was removed Aug. 21.

The first recorded catch of pink salmon at Karluk was made in 1901. From then until 1910, two years produced a few pinks, one year showed a yield of 233,000, while in five years no catch was reported. Beginning in 1910, however, pinks were taken each even year in considerable numbers but in negligible quantities in the odd years. (See Table 14.) This violent fluctuation is characteristic of the pink-salmon runs at Karluk, just as in many other places in Alaska.

In the early years of fishing at Karluk, pink salmon were not desired and were not canned. Untold thousands were taken in the seines with red salmon, hauled on the beaches and left there to die. It was said that at times the beaches were covered knee deep with dead pink salmon. It is also conjectural whether this tremendous waste occurred only in the first 20 years of fishing at Karluk; perhaps the practice of dumping pinks was followed in more recent years. There seems to be no other explanation of the total absence of this species in Karluk catches in some years, for in 1900 when "humpbacks came in myriads" to Red River, not one was reported at Karluk. It is probable, however, that pinks were equally abundant at both places. In the last 17 years, the fluctuations in catch of pinks has been very pronounced and show a marked 2-year cycle with heavy runs on the even years and light runs on the odd—the same as in most other localities in western Alaska. In 1916 and 1924, approximately 2,500,000 were taken while in all the other even years, except 1926, the catch reached fairly high levels.

The small run in 1926, following the heavy run of 1924, is particularly interesting since it was naturally to be expected that the enormous escapement in 1924 would have produced a large run in 1926. The run of 1926 was, however, almost as poor as the runs of the odd years; the total recorded catch of this species at Karluk was less than 90,000 and the escapement at the weir was only about 15,000. The escapement of pinks in 1924 was tremendous and, while there was no accurate count, a conservative estimate was made that it was in excess of 4,000,000. These fish all entered the stream during the later half of July and in August, and by the 21st of August so many had died that their dead bodies blocked up the weir and it was impossible to maintain it. The number of dead, spawned-out, pinks was so great that their decaying bodies apparently so polluted the water that nothing could remain in the stream and survive. Unspawned salmon of all species, salmon fry and fingerlings, trout and various small fishes were reported to have died in large numbers. The tremendous mortality is indicated by the fact that on Karluk Beach the clean bones of the dead salmon that had drifted downstream onto the beach were rolled up into solid balls by the action of the surf. It was reliably reported that the beach for miles was covered by these remarkable aggregations of salmon bones. With such conditions existing in the river it seems quite probable that the failure of the spawning of 1924 to produce a run in 1926 may be ascribed to the fact that the same conditions that caused the death of all kinds of fish also acted unfavorably on the eggs that had been deposited. It is certain that these eggs did not survive, since comparatively few pink salmon fry were observed leaving the river in the spring of 1925. The red-salmon spawning of 1924 was also unfavorably affected as was shown by the poor run of 1929. Everything indicates, therefore, that in 1924 the spawning grounds of the Karluk were overcrowded with spawning pink salmon, and that this overcrowding was responsible for the poor run of 1926. This statement should not be taken, however, as indicating that such overcrowding is in any way a common occurrence. On the contrary, it is believed that such overcrowding is extremely rare, especially in the case of runs that are exploited commercially.

Comparatively few chum salmon are taken at Karluk. They are not regarded as a valuable fishery resource. Available records show that they have been taken in each year from 1915 to 1927, and that the largest catch was made in 1926, while none was reported before 1912.

NORTHWEST COAST OF KODIAK ISLAND DISTRICT

This district embraces the waters of Kodiak Island from Cape Uyak on the south to and including Whale Passage at the eastern end of Kupreanof Strait. The coast line is broken by several deep bays into which flow several streams used by salmon. The most noted of these is Uganik River, while on the outer coast, between Cape Ugat and Cape Kuliuk, Little River is the only conspicuous producer of salmon. The data are presented in Table 19.

The history of the Little River fishery is almost a duplication of that of Red River, and it dates back to about the same time, having begun more than 30 years ago. This is primarily a red-salmon stream, as there are no recorded catches of other species except in four years when chums and pinks were taken, the total catch for any year being less than 1,000 fish. The earliest recorded catch of salmon at Little River was made in 1897, the next in 1900, and then beginning in 1904 the fishery was continued without interruption until 1918, in which year no salmon were reported from that stream. Fishing was resumed in 1919 and carried on through the next two seasons. Following a hiatus of three years, from 1922 to 1924, small catches were made in 1925 and 1926, but 1927 was again unproductive so far as records show. The maximum catch in 1904 was reported as 246,131 fish, but as the catch in no subsequent season even remotely approached that figure, the accuracy of the number in 1904 is open to question. The average annual catch from 1900 to 1911, not including the doubtful record for 1904, was over 50,000 red salmon; but in 1912 the catch dropped to 5,583, and only once since then did it exceed 10,000. In considering this record, little doubt exists that intensive fishing at Little River between 1904 and 1911 depleted and almost destroyed its red-salmon run, until a locality that was once very productive, considering its size, was abandoned as fished out.

TABLE 19.—*Salmon catch and fishing appliances used in the northwest coast of Kodiak Island district, 1896 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Kupreanof Strait:												
1915	131		1, 805		20, 267							
1916	899	1, 486	49, 267	86	10, 025							
1917	1, 328	1, 587	20, 496	114	15, 312							
1918	2, 358	5, 600	88, 056	123	16, 807							
1919	744	313	11, 757	47	3, 500							
1920			1, 887		2, 106							
1921			202		2, 535							
1922		19	2, 181	1	1, 626							
1923	33	17	1, 381		2, 440							
1924				4	164							
1926	720		5, 106		91							
Little River:												
1897					6, 000							
1900					23, 100							
1904					246, 131							
1905					80, 568							
1906					34, 925							
1907					81, 862							
1908					85, 763							
1909					29, 360							
1910					47, 037							
1911					27, 292							
1912					5, 583							
1913					1, 200							
1914					9, 640							
1915			58		10, 902							
1916					1, 181							
1917					4, 273							
1919		109	547		2, 279							
1920					842							
1921					1, 361							
1925			71		503							
1926		229	649	1	2, 689							
Rocky Point:												
1923		691	2, 353		17, 810							
1924	572	221	11, 529		14, 625							
1925		3, 061	8, 394		4, 581							
Seven Mile Beach:												
1924		37	93		1, 888							
1925	330	223	293		16, 490							
1926	921	2, 598	15, 845	5	82, 101							
1927	1, 043	2, 945	5, 656		37, 718							
Shelikof Strait:												
1924	1, 290	1, 077	149, 207	3	111, 277							
1925	7	932	493		5, 057							
1926	594	5, 086	15, 196	10	41, 595							
1927	2, 164	19, 420	158, 265	29	38, 896							
Spiridon Bay:												
1916			4, 162									
1917			7, 326		45							
1919		935	7, 038									
1923	2	733	38, 922	1	398							
1925	13	59	72, 727		294							
1926	12	9, 752	75, 651	1	64							
1927	5, 745	44, 103	196, 698	327	2, 159							
Terror Bay:												
1923			40, 739									
1924		981	53, 286									
1925	4	3, 138	12, 334		1, 116							
1926		218	62, 570		51							
1927	273	637	5, 710		2							
Uganik Bay:												
1896					365, 850							
1897					22, 130							
1898					29, 846							
1899					154, 856							
1900					143, 260							
1901					100, 000							
1902					100, 000							
1903					50, 000							
1904					82, 288							
1905					2, 272							
1906					34, 201							
1907					102, 640							
1908					125, 869							
1909					226, 477							
1910			2, 185		128, 920							
1911			7, 000		133, 274							
1912	62		20, 000		74, 041							
1913			3, 162		48, 265							
1914					55, 998							
1915			3, 221		24, 210							
1916	2, 850		87, 346		15, 393							
1917		1, 413	46, 931		7, 752							
1918		600	374, 338		2, 300							

TABLE 19.—*Salmon catch and fishing appliances used in the northwest coast of Kodiak Island district, 1896 to 1927*—Continued

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Uganik Bay—Contd.												
1919		775	2, 270		10, 234							
1920		26	643		5, 369							
1922	1, 312		15, 696		1, 640							
1923	2, 203	2, 802	61, 993	30	6, 698							
1924	2, 284	10, 252	247, 956	28	4, 390							
1925	1, 771	32, 674	94, 200		4, 646							
1926	9, 660	33, 254	961, 012		274, 390							
1927	24, 302	89, 560	798, 406	769	125, 715							
Ugat, Cape: 1927	1, 880	6, 874	16, 088	19	26, 957							
Uyak Bay:												
1911			12, 000									
1912			6, 643									
1913			7, 936									
1917	40	1. 681	3, 198		11, 146							
1918		15, 794	69, 459		7, 824							
1919		132	231		11, 959							
1920			36, 180									
1921					10, 511							
1922	434	30, 545	317, 616		2, 067							
1923	721	1, 316	8, 526		40, 647							
1924	4, 597	9, 972	417, 751		25, 587							
1925	4, 881	26, 932	98, 327	11	160, 163							
1926	10, 818	44, 430	1, 405, 906	8	228, 599							
1927	7, 239	55, 866	673, 986	146	135, 388							
Viekoda Bay: 1927	2, 537	5, 465	65, 201	349	4, 924							
Zachar Bay:												
1919		3, 514	3, 247									
1920		628	1, 976									
1922	12. 000		34, 525									
1924	500	6, 782	130, 471		77							
1925	1, 230	15, 319	43, 562		10, 692							
1926	2, 699	9, 226	112, 581		5, 605							
1927	2, 213	16, 209	73, 346	86	2							
Unallocated: 1920	3	32	1, 275		2, 153							
Total:												
1896					365, 850							
1897					28, 130							
1898					29, 846							
1899					154, 856							
1900					166, 360							
1901					100, 000							
1902					100, 000							
1903					50, 000							
1904					328, 419							
1905					82, 840							
1906					69, 126							
1907					184, 502							
1908					211, 632							
1909					255, 837							
1910			2, 185		175, 957							
1911			19, 000		160, 566							
1912	62		26, 643		79, 624							
1913			11, 098		49, 465							
1914					65, 638							
1915	131		5, 084		55, 379					10	600	
1916	3, 749	1, 486	140, 775	86	26, 599					8	500	
1917	1, 368	4, 681	77, 951	114	38, 528	3	400			4	300	1
1918	2, 358	21, 994	531, 853	123	26, 931	6	520					1
1919	744	5, 778	25, 090	47	27, 972							1
1920	3	686	41, 961		10, 470	1	60					
1921			202		14, 407							
1922	13, 746	30, 564	370, 018	1	5. 333	2	290	1	200	2	100	
1923	2, 959	5, 559	153, 914	31	67, 993	9	5, 775	1	150	10	1, 300	
1924	10, 533	30, 399	1, 159, 500	38	269, 285	7	1, 125	1	150	6	900	2
1925	8, 243	83, 270	330, 894	11	208, 599	12	1, 875	1	150	23	1, 180	2
1926	26, 018	109, 879	2, 669, 712	35	676. 780	15	1, 900			57	4, 680	3
1927	49, 650	260, 499	2, 151, 621	1, 754	410, 657	10	2, 365	2	200	94	9, 125	14

NOTE.—No catch was reported in the years omitted from the several sections of the foregoing table. The unallocated catch in 1920 was made at Salmon Creek, an unidentified locality. The catch at Uganik in 1901, 1902, and 1903 was estimated and a corresponding reduction made from Karluk catches, as in those years Uganik fish were not segregated from Karluk fish.

The physical characteristics of Little River are much like those found at Karluk. The stream enters Shelikof Strait through a gravel spit which in the course of years has been thrown up by the sea across the mouth of the stream. This has caused the formation of a lagoon which covers an area of approximately one-half square mile, affording an easy fishing ground at times when operations outside the spit were stopped by heavy surf—one to be preferred at all times, and perhaps used without scruples most of the time, as in the years of greatest production, enforcement and observance of the fishery law were almost unknown, just as they were at Red River. If fishing at Little River had always been conducted in accordance with the law of 1906, it is unlikely that a run once yielding an annual catch of over 50,000 red salmon could be literally destroyed within a decade, yet that is exactly the history of the Little River fishery. The average yield of 50,000 fish was, obviously, more than this small fishery resource could support, but one might suppose, on the basis of what is known of the productivity of other salmon runs, that the annual catch of Little River might well have been stabilized at some thirty or forty thousand.

Uganik Bay has one important red-salmon stream which is tributary to East Arm. Development of a fishery there was nearly contemporaneous with the establishment of canneries at Karluk, although the first recorded catch of salmon was made in 1896. It is known, however, that prior thereto a saltery was operated in that locality and obtained its supply of salmon from this stream. It is also known that the canneries at Afognak Bay obtained a part of their fish from bays on the northwest coast of Kodiak Island, notably Uganik, and that this district should be credited with catches as follows: 220,038 in 1889, 191,237 in 1890, and 131,250 in 1891. In accordance with that fact, it may be safely asserted that the history of the fishery began before 1890. Recognition of the value and importance of the run was manifested by the erection of a cannery at the entrance of East Arm in 1896. After the first season, packs were small, although augmented by transfer of salmon from other localities, and the plant was not reopened after 1900. Thereafter Uganik salmon were packed chiefly at Uyak and Karluk.

Red salmon from Uganik were especially valuable on account of their large size and excellent quality, and fishermen employed methods that would secure the largest catches in total disregard of any moral or legal objection to their use. Even before 1900 the stream was barricaded and efforts were directed toward maintaining a blockade that would prevent the escapement of all salmon. Evidently no concern was felt for the preservation of a valuable run of salmon. The Uganik Bay section of Table 19 shows comparatively large catches of red salmon in 1926 and 1927, which might make it appear that the stream in East Arm had again become a notable producer; but that view would be erroneous as the catches referred to were in large part taken by traps near the entrance of Uganik Bay and were a part of the Karluk run as was shown by tagging experiments conducted in 1927.[14]

No pink salmon were reported from Uganik Bay until 1910, and no large catch was made until 1916. In 1918, the catch was 374,338, but in 1920 it was only 643. In 1920 and 1921 there was little or no demand for pink salmon as the heavy packs of 1918 and 1919 had glutted the market and large surpluses were on hand. After 1922, the market for pink salmon had so far recovered from the depression of 1920 as to warrant resumption of packing generally, which explains the larger catches in late years. For the same reason, coho and chum salmon were not taken in appreciable numbers until after 1922.

The catches reported from Kupreanof Strait from 1915 and 1926 were made largely by one trap and a few gill nets set along the south shore of Raspberry Island. There are no salmon streams worthy of mention in that locality. Catches made there came from runs to other places, along the west coast of Kodiak and Afognak Islands, and the probability is that the greater movement was toward the streams southward as far as Karluk. Especially good catches of reds and pinks were taken from 1915 to 1918, but since then the district produced few fish of any species during the period covered by this report. Since 1927 there has been renewed activity that will be treated in a future report.

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[14] Salmon-tagging Experiments in Alaska, 1927 and 1928. By Willis H. Rich and Frederick G. Morton. Bulletin, U. S. Bureau of Fisheries, Vol. XLV, 1929, Document No. 1057. Washington.

The very peculiar history of the catch of red salmon in Uganik Bay is shown graphically in Figure 7. The large catches made in 1926 and 1927 have been explained above, and it is the history of the fishery from 1896 to 1920 that is of special interest. There apparently have been three periods of relative abundance separated by periods of very low productivity and ending in almost complete elimination of the commercial fishery. So far as our records show the catches were entirely comparable, but it is extremely difficult to account for such fluctuations on the assumption that we are here dealing with a single run. The periods of maximum and minimum abundance are too widely separated in time to be accounted for as ordinary cycles of abundance due to the influence of dominant age groups and the perpetuation of good and poor runs, and it seems most unlikely that such extreme yet regular fluctuations would be due to the influence of evironmental conditions. The only explanation that can be offered is that data are incomplete and that these peculiar cycles, if they may be so called, are due to differences in the conduct of the fishery. It seems probable that, as the race of Uganik red salmon declined in abundance the fishery changed and took fish from other runs, just as the fishery since 1926 has taken Karluk River fish. On the other hand the periods of apparent scarcity may have been due to a failure to properly report fish actually taken in Uganik Bay. Whatever the true explanation of these peculiarities in the record, certain facts are quite clear: The run of Uganik red salmon was originally one of considerable magnitude and value but through exhaustive fishing, probably accompanied by unlawful and destructive methods, the run has been so reduced that it is now practically worthless as a commercial fishery resource. No natural conditions such as existed at Red and Little Rivers operated in favor of the Uganik run; no ocean surf struck the Uganik beaches and storms rarely or never interrupted fishing to give the fish an opportunity to enter the stream. Everything was in favor of the fishermen. As in the case of Red River, it seems possible by adequate regulations to rehabilitate the run here to its former productivity. A counting weir has been operated in Uganik River since 1928, and the escapement, although small, seems sufficient as a basis on which the run may be built up. The course of this rehabilitation will be watched with great interest.

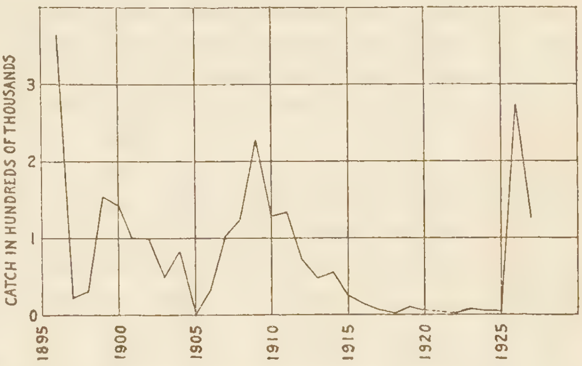

FIGURE 7.—Catch of red salmon at Uganik

Rocky Point, Seven Mile Beach, and Shelikof Strait are not localities where salmon runs are produced but merely points where salmon traveling to streams chiefly along the northwest coast of Kodiak Island are intercepted. The only exception to this statement is that one small stream at Seven Mile Beach attracts a few salmon. Traps have been recently introduced into these waters and gill netting and beach seining at Seven Mile Beach began several years ago at the time when placer mining on the beach induced a few prospectors to settle there for several years. These men varied their activities by fishing in the summer time when the run of salmon was at its height, and sold their catches to the cannery at Uyak. Similar operations were carried on at Long Beach on the north side of the entrance to Uyak Bay where a small stream enters Shelikof Strait. The bulk of the catch here came, however, from salmon on their way to larger streams, most likely to Karluk River.

This district includes four bays which in later years have attained some distinction as important localities, due to the advent of new canneries into that region. They are Spiridon, Terror, Uyak, and Zachar Bays. Little attention was paid to fishery possibilities in these waters by the two canneries operating chiefly at Karluk, or by the one cannery at Kodiak, until 1922 when two floating canneries appeared in Uyak Bay and made surprising catches of pink salmon in Uyak and Zachar Bays. In 1923 another new cannery was opened in Uganik Bay, and the long-established companies operating at Karluk spread their activities into these heretofore neglected places, raising the catch to new levels. These increases affected pink salmon largely, although there were also sizable catches of coho and chum salmon, and a notable catch of red salmon in Uyak Bay in the last three years.

Viekoda Bay and Cape Ugat are set out as separate localities although only the record of catches here in 1927 are available. It is probable, however, that future catches will be reported from these localities, and for that reason they are here kept distinct.

The intensive fishing operations in most of these localities have been of such recent development that it is impossible to draw any detailed conclusions from the available data. It is apparent, however, that this expansion of the fishery draws primarily upon the species other than red salmon. The red-salmon resources had been fully exploited in the past, and it had been many years since every possible source of these fish was discovered and fished to, if not beyond, the limit that the supply could withstand without depletion. In this recent development of the fishery for the cheaper grades of salmon, there have been large increases in the catches of chums, cohos, and pinks, but the pink-salmon catch has greatly exceeded the others in all localities in this district. A distinct tendency is shown for the pink salmon to run more heavily in the even years, although excellent catches were made in 1927 in Uganik Bay and in the Uyak Bay (including Spiridon and Zachar Bays.) Pink salmon were unquestionably much more abundant in 1927 than in the odd years that immediately preceded, and it would appear likely that the odd-year run is building up to approximately the magnitude of the even-year runs.

The only evidence of serious depletion of salmon in any subdivision of this district is seen in the red-salmon runs at Little River and at East Arm, Uganik Bay. In the former the situation is desperate and merits immediate attention, while at Uganik there is hope that by strict observance of present regulations the fishery will survive and rebuild itself into its former proportions.

AFOGNAK ISLAND DISTRICT

This district includes the coastal waters of the north shore of Raspberry Island, all the shores of Afognak Island (except those bordering on Marmot Bay) from Afognak Village westward and northward to Tonki Cape, Shuyak Island, and all other adjacent islands.

Afognak Village, one of the oldest settlements in western Alaska, is located on the southern shore of Afognak Island, a few miles south of Afognak Bay, perhaps largely for the reason that a good red-salmon stream at the head of the bay afforded an ample supply of fish for domestic needs. Rather large catches were formerly made for such purposes. It may also be true that salmon from this stream were used commercially long before the erection of canneries in that section, but no authentic records of this are extant. It is known, however, that two canneries were built at the head of the bay in 1889 and made packs in 1889 and 1890. In 1891, these plants were not operated, but the fish which otherwise would have been taken by them from near-by streams were packed at Karluk and credited to the Afognak canneries. The pack in 1889, according to Moser, was 41,912 cases of red salmon, which, at 14 fish per case (a fair average for this region), gives a catch of 586,768 salmon. In 1890 the pack was 36,426 cases, and the computed catch was 509,964. Records show that one cannery operated in 1891, making a pack of 25,000 cases, representing a catch of approximately 350,000 salmon.

No information is available showing where these catches were made. It is safe to assume that they were not taken entirely from Afognak waters, else the production then was vastly greater than it has been in subsequent seasons. Part of the salmon canned by these plants undoubtedly came from Uganik Bay and other waters of Kodiak Islands, as many "old timers" now living at Afognak and Kodiak bear witness. Probably not more than 50 per cent of the catches in these three years came from Afognak streams and 75 per cent of that half from the streams of the west coast of Afognak, leaving the remaining 25 per cent as the catch at Afognak, Little Afognak, and Izhut Bays in the Marmot Bay district. If these rough estimates are even approximately correct, the catch in this district in 1889 was 220,000 red salmon; in 1890, 190,000; and in 1891, 130,000.

Salmon fishing was presumably carried on at Malina, Paramanof Bay, and Seal Bay long before the earliest dates recorded here, but no record of catches could be found. Malina was undoubtedly one of the important fishing grounds of the canneries located for a few years on Afognak Bay, or until the Afognak Reservation was established in 1892. From that year until 1907, the earliest year for which records are available, it seems likely that the natives of Afognak Village continued to fish at Malina and sold their catches to salters at Kodiak or salted them right at the fishing grounds for ultimate sale at Kodiak. The same situation may have existed also at Seal and Paramanof Bays. All such operations, however, were in violation of the terms of the presidential proclamation creating the Afognak Fisheries Reservation, as the right to fish in the reservation was restricted to the taking of salmon for domestic purposes only, and there are, naturally, no records of catches made during this period.

In 1911, representations were made to the Department of Commerce that the natives of Afognak Island were dependent upon these fisheries for a livelihood, and that they would suffer extreme poverty and distress if commercial fishing could not be resumed, and in April, 1912, a departmental order was promulgated opening the reservation to commercial fishing by natives who were residents of Afognak Island conditional upon their obtaining a fishing license from a designated agent of the Government. During that year salmon were salted at Malina, Paramanof, and Seal Bays, but much of the pack was lost, due to faulty curing, and to the interruption of operations in the middle of the season by the eruption of Katmai Volcano. Most of the catch in that year went to the new cannery at Kodiak, as it did for years thereafter, or until 1921, when a cannery was built at Uzinki. Since then two more canneries were opened and now get a share of Afognak fish.

All streams in this district are small, those of Malina, Paramanof, and Seal Bays being the most important. Malina Creek empties into Shelikof Strait at a point exposed to westerly winds, which frequently interrupt fishing there, a condition that should make for a larger escapement of salmon than at the other fisheries located near the heads of bays in quiet places where similar interruptions do not occur. These fisheries have been fairly productive of red salmon, and the district as a whole shows no such evidences of serious depletion as have been observed in some other localities. It would be unreasonable, however, to suppose that there can be much increase in the productivity of these streams so far as red salmon are concerned. The spawning grounds are too limited, as the lake shores are rocky and precipitous and the tributary streams are small. The other species fare better, however, as several miles of creek beds below the lakes are open to them for spawning. The data are presented in Table 20.

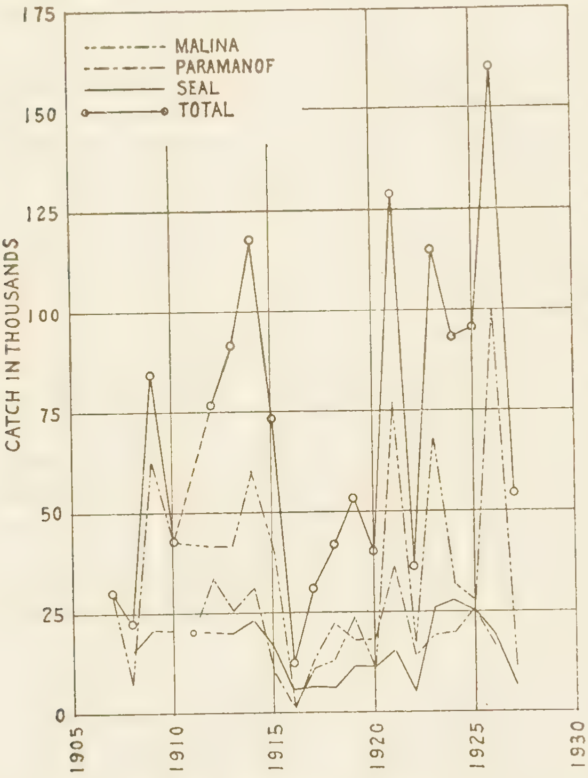

FIGURE 8.—Catch of red salmon at Malina, Paramanof, and Seal Bays

The catch of red salmon is shown graphically in Figure 8. This presents the catch in each of the three most important localities and for the entire district. There was a marked reduction in the catch in all localities during the 5-year period beginning with 1916—a condition that was in all probability due primarily to the unfavorable conditions in the spawning grounds that obtained for several years after the Katmai eruption of 1912. The fisheries have shown a remarkable recovery since 1920, however, and in recent years have been fully as productive as at any time since our records began. There have been wide fluctuations in the annual catches, but, with the exception just considered, these fluctuations appear to be due to natural causes and without special significance. There is some evidence of a cyclic change at 5-year intervals, but we have not considered it worth while to make a detailed analysis of this on account of the comparatively few years in the series that may be considered as normal.

TABLE 20.—*Salmon catch and fishing appliances used in the north and northwest coast of Afognak Island district, 1907 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Big Bay, Shuyak Island:												
1926	7,000		2,500		1,500							
1927	11,866		4,800		583							
Devils Bay:												
1923			6,149									
1926		54	4,949									
Malina:												
1907	1,800				30,000							
1908					6,860							
1909					63,240							
1910	7,200				43,285							
1912			23,311		42,996							
1913			8,410		42,136							
1914	9		19,505	150	60,314							
1915	23	15	5,424		42,347							
1916		129	1,350		2,833							
1917			1,315		11,516							
1918		3	7,247		13,899							
1919		248	1,098	22	23,037							
1920			10,995		10,728							
1921	71	191	5,923	4	77,147							
1922	2,905	82	65,366		17,123							
1923	1,328	98	19,729	15	68,381							
1924	34	376	18,269	316	32,203							
1925	3,369	241	9,701	32	28,031							
1926	4,240	623	65,766	39	100,732							
1927	4,276	1,744	25,394	200	11,879							
Paramanof Bay:												
1911					20,103							
1912	621		9,860		34,782							
1913			288		26,958							
1914			77		31,737							
1915			9,102		10,611							
1916					1,697							
1917	185		55,924		13,042							
1918		118	40,500		22,335							
1919	35	235	12,344		18,568							
1920		35	15,385		18,009							
1921		1,004	5,423	6	36,995							
1922		485	9,731	7	14,228							
1923	34	83	32,601		19,724							
1924	4	3	10,325	3	20,919							
1925	27	2,842	20,913	5	27,399							
1926	11	537	11,678	4	17,465							
1927	1,482	1,369	124,295	14	8,566							
Perenosa Bay:												
1915					549							
1927	5,627		19,183		19							
Raspberry Strait:												
1926					891							
1917					202							
1919			39		129							
1922	1,112											
1923	74	48	762		461							
1924	1,284				2,415							
1925	35											
1926	2,719	140	8,702	4	10,309							
1927	4,137	9,006	146,633	549	25,590							
Red Fox Bay:												
1925	936											
1927			15	1	178							
Seal Bay:												
1908					15,584							
1909	8,374		26,046		21,337							
1913			859		20,123							
1914	349		39,461		23,597							
1915	59		8,363		17,962							
1916	51	2	117		6,883							
1917	462		20,351		6,990							
1918	6		2	1	6,544							
1919		57	42,941	27	12,157							
1920			190		11,733							
1921			447	2	15,201							
1922			154	6	5,426							
1923	24	4	3,325		26,867							
1924	13		3,388	5	28,071							
1925	9,571		15,119	26	26,639							
1926	8,792		26,124		19,686							
1927	5,303	1	2,330	21	7,669							
Shuyak Bay:												
1913			318		3,490							
1914	1,812		610		2,987							
1915	5,344		6,191		1,838							
1916			825		331							
1923	24		4,326		407							
1924	10,025		5,024		1,127							
1925	13,704		7,850		2,999							
1926	3,986		7,840		183							
1927	2,200				130							

TABLE 20.—*Salmon catch and fishing appliances used in the north and northwest coast of Afognak Island district, 1907 to 1927*—Continued

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Shuyak Strait:												
1920			12,351		291							
Tonki Bay: 1927	3		18									
Unallocated:												
1924	38	45	3,001		8,513							
1925	961	987	4,926		11,679							
1926	5,890	898	27,707	12	12,018							
1927	121											
Total:												
1907	1,800				30,000							
1908					22,444							
1909	8,374		26,046		84,577							
1910	7,200				43,285							
1911					20,103							
1912	621		33,171		77,778	14	1,400					
1913			9,875		92,707	7	700			2	100	
1914	2,170		59,653	150	118,635	7	700			2	100	
1915	5,426	15	29,080		73,307	7	1,050					
1916	51	131	2,292		12,635	7	700					
1917	647		77,590		31,750	6	750					
1918	6	121	47,749	1	42,778	5	500					
1919	35	540	56,422	49	53,891	7	700					
1920		35	38,921		40,761	7	700					
1921	71	1,195	11,793	12	129,343	9	1,125					
1922	4,017	567	75,251	13	36,777	10	1,435					
1923	1,484	233	66,892	15	115,840	12	1,425					
1924	11,398	424	40,007	324	93,248	11	1,425					
1925	28,603	4,070	58,509	63	96,747	10	1,120					
1926	32,638	2,252	115,266	59	161,893	14	1,995					
1927	35,015	12,120	322,668	785	54,614	11	1,460					

NOTE.—The unallocated catches were reported from Afognak Island in 1925, 1926, and 1927, and from the west coast of Afognak Island in 1924.

The catch of pink salmon in this district was fairly constant from 1912 to 1925, and is remarkable in that it does not show the marked fluctuations in alternate years that are such characteristic features of pink-salmon runs throughout most of western Alaska. The record shows no definite tendency toward increased catches in either the odd or the even years, although extreme variations in this respect are found on Kodiak Island and on the mainland opposite Afognak Island. As will appear later, a similar condition exists in Marmot Bay and along the southeastern shore of Kodiak Island.

The fact that in this small restricted district no evidence is found of the 2-year cycle leads one to speculate upon the possibility of building up the "off" years in those districts where the good runs are confined to alternate years. The ultimate causes that originally established the 2-year cycle can not, of course, be known and we, at least, do not care to speculate on this, although they were unquestionably environmental and possibly associated with conditions in the sea, since conditions in fresh water are much more likely to be variable in localities as widely separated as those which show this markedly greater abundance on the even years. Whatever the cause it must have been extremely widespread, since the cycle as now known has prevailed for many years over the whole of central and western Alaska. Almost everywhere throughout this vast area there have been good runs on the even years and poor runs on the odd years, and only occasionally (as in 1927) has there been any tendency for conditions to change and bring good runs on the odd years. The fact that the pinks are exclusively 2-years old at maturity accounts, of course, for the perpetuation of the 2-year cycle once it was started and, conversely, the rigid maintenance of a 2-year cycle over a vast area and over a long period of time is corroboratory evidence of the fact that pinks are exclusively 2-year fish.

No good reason is apparent why the runs have not increased in the odd years since there are almost invariably a few pinks to be found in all streams on the odd years. It would seem probable that even a small breeding population would either build up in the course of time or would disappear entirely if the density of spawning population was below that required for effective propagation. It is possible, of course, that the meager runs on the odd years are composed of "strays" from other streams that do support good runs, but even this does not explain the maintenance of poor runs over a long period of time unless it is assumed that the breeding of the few fish found in the streams on the odd years is entirely without result. Too little is known of the habits of the pink salmon, and particularly of their "homing instinct," to justify definite conjecture; but the fact remains that the poor runs on the odd years showed no general tendency to increase until 1927.

It would appear from a consideration of the few available facts that there is no real reason why good runs may not be maintained on the odd years as well as the even. If this could be brought about, the production of pink salmon throughout the greater part of western Alaska would be practically doubled. It seems doubtful (in view of the fact that the odd-year runs have not increased in the past before they were commercially fished) that such an accomplishment can be effected solely by regulation. It would seem to require artificial propagation on a tremendous scale, aided by rigid protection, but if runs could be established on the odd years their value would well repay the effort. The possibility of doing this depends, however, upon the extent to which the pinks return to their parent streams, a matter that is now under investigation. Once this question is settled, if favorable, consideration might well be given to the opportunity here presented of enormously increasing the productivity of a large area.

This district has never produced many chums or kings, the largest catches of both species having been made in 1927, the last year considered in this report. The catch of cohos was irregular and small up to 1924, but in that year and each subsequent year good catches have been made, an increase that was doubtless due to increased intensity of fishing.

Viewing the district as a whole, a notable increase in the catch of all species has come about in the last seven years, yet that is not in itself evidence that the runs are increasing and that the supply of salmon is larger than ever before. It is much more likely due to the fact that greater efforts are being made to catch the salmon. On the other hand there is no evidence that the salmon runs in this district have been depleted, but it must be borne in mind that small streams, such as these, can be easily overfished and a run of salmon depleted in a few years. The development of the fishery should be carefully watched, and fishing operations should have close supervision if disastrous consequences are to be averted.

MARMOT BAY DISTRICT

The Marmot Bay district embraces Marmot Bay, its several arms indenting the southern shore of Afognak Island from Tonki Cape on the east to the narrows between Afognak and Whale Islands on the west; the eastern part of Whale Island; and all waters along the north shore of Kodiak Island from Karluk Strait eastward to Uzinki Narrows and North Cape on Spruce Island, with all adjacent islands.

TABLE 21.—*Salmon catch and fishing appliances used in the Marmot Bay district, 1904 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Afognak Bay:												
1918	3,470		910		836							
1919	5,203											
1920	6,854				7							
1921	4,197											
1922	18,034				117							
1923	15,018	1	354	28	758							
1924	10,766											
1925	6,456											
1926	9,309		5	2	90							
1927	4,064		486		2							
Anton Bay: 1927	43	2,586	88,217	5	9							
Camel Rock:												
1926	1,429	3,935	15,804		23							
1927	189	1,057	39,879	2	7							
Danger Bay:												
1912	327											
1913	1,146		20,818		451							
1914			2,812		72							
1915	3		4,075		14							
1916	4,194		1,345									
1917	1,556		22,581		184							
1918	1,012											
1919			5,871		27							
1920	840											
1922	2,777		16,680		14							
1923	2,225		40,177									
1924	4,950											
1925	3,721		6,935		76							
1926	1,117	384	5,113		23							
1927	3,569	29	2,163		5							
Doctor Bay:												
1916			6,893									
1922	995	1	32,388		29							
1923	588	539	68,241		59							
1924	910	346	97,905									
1925	168	1,520	54,203		44							
1926	57	981	1,098		2							
1927		325	4,177	2								
Izhut Bay:												
1910					11,957							
1912	165				195							
1913			15,793		3,188							
1914			940		3,426							
1915			9,130		1,216							
1916	998											
1917			6,910		17,638							
1919					1,973							
1920					3,364							
1921	1	5	2	2	2,771							
1923	544		233		13,720							
1924	25	6	4,580	3	8,174							
1925	276			11	8,639							
1926	547		146		574							
1927	917				129							
Kizhuyak Bay:												
1904					9,842							
1907	1,892				36,341							
1908	14,500				31,804							
1909	5,550				19,079							
1910	3,065				29,196							
1911					17,319							
1912			21,445		23,341							
1913			146,804									
1914			3,101		2,149							
1915		12	266		7							
1918			14,880									
1923	7	11	9,673	1	722							
1924	1,785	32	2,081		68							
1925	1,258	2	13,751		1,353							
1926	2	5,504	28,764		10							
1927	907	2,638	67,670		74							
Lena Bay: 1927		1,563	3,213		4							
Little Afognak Bay:												
1909	12,270				16,603							
1912	2,024		438		7,281							
1913	4,150		1,443		8,673							
1914	2,422				7,266							
1915	5,876		5,393		10,702							
1916	16,024		2,658	2	34,898							
1917	1,496		261		22,157							
1918	1,881		23,042		7,884							
1919	5,179	119	2,112		23,335							
1920	5,128		34,374		8,584							
1921	1,867	3	97	8	41,329							
1922	11,609		2,141	17	5,241							
1923	5,161		434	3	17,411							
1924	20,922		5,237	148	12,689							

TABLE 21.—*Salmon catch and fishing appliances used in the Marmot Bay district, 1904 to 1927*—Con.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Little Afognak Bay—Con.												
1925	1,613	-------	111	-------	5,893	-------	-------	-------	-------	-------	-------	-------
1926	9,778	1	1,492	23	4,866	-------	-------	-------	-------	-------	-------	-------
1927	9,552	-------	80	5	159	-------	-------	-------	-------	-------	-------	-------
Unallocated:												
1923	123	-------	-------	-------	90	-------	-------	-------	-------	-------	-------	-------
1926	-------	15	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Total:												
1904	-------	-------	-------	-------	9,842	-------	-------	-------	-------	-------	-------	-------
1907	1,892	-------	-------	-------	36,341	-------	-------	-------	-------	-------	-------	-------
1908	14,500	-------	-------	-------	31,804	-------	-------	-------	-------	-------	-------	-------
1909	17,820	-------	-------	-------	35,682	-------	-------	-------	-------	-------	-------	-------
1910	3,065	-------	-------	-------	41,153	-------	-------	-------	-------	-------	-------	-------
1911	-------	-------	-------	-------	17,319	-------	-------	-------	-------	-------	-------	-------
1912	2,516	-------	21,883	-------	30,817	6	600	-------	-------	-------	-------	-------
1913	5,296	-------	184,858	-------	12,312	3	300	-------	-------	2	100	-------
1914	2,422	-------	6,853	-------	12,913	3	300	-------	-------	2	100	-------
1915	5,879	12	18,864	-------	11,939	3	450	-------	-------	-------	-------	-------
1916	21,216	-------	10,896	2	34,898	4	400	-------	-------	-------	-------	-------
1917	3,052	-------	29,752	-------	39,979	2	250	-------	-------	-------	-------	-------
1918	6,363	-------	38,832	-------	8,720	1	100	-------	-------	-------	-------	-------
1919	10,382	119	7,983	-------	25,335	3	300	-------	-------	-------	-------	-------
1920	12,822	-------	34,374	-------	11,955	3	300	-------	-------	-------	-------	-------
1921	6,065	8	99	10	44,100	4	500	-------	-------	-------	-------	-------
1922	33,415	1	51,209	17	5,401	9	1,285	-------	-------	9	720	-------
1923	23,666	551	83,259	32	32,760	9	975	-------	-------	-------	-------	-------
1924	39,358	384	109,803	151	20,931	6	775	-------	-------	-------	-------	-------
1925	13,492	1,522	75,000	11	16,005	4	550	-------	-------	-------	-------	-------
1926	22,239	10,820	52,422	25	5,588	7	945	-------	-------	-------	-------	-------
1927	19,241	8,198	205,885	14	389	6	680	-------	-------	-------	-------	-------

NOTE.—No catch reported in the years omitted from this table. The unallocated catch in 1923 was 123 cohos from Spruce Island and 90 reds from Wooded Islet; in 1926, it was 15 chums from Whale Island.

In our discussion of catch statistics for the Afognak Island district mention was made of the pack of two canneries on Afognak Bay in the three years of their operation, and it was shown that on the basis of 14 fish per case, the catch of red salmon was as follows: 586,768 in 1889, 509,964 in 1890, and 350,000 in 1891. As there explained, this entire catch certainly was not taken from Afognak waters, and we allocated to Marmot Bay 25 per cent of the totals, which were as follows: 146,692 in 1889, 127,490 in 1890, and 87,500 in 1891. They are not shown in the table because of the unsatisfactory nature of the allocation we have had to make.

As already explained in another section of this review, Afognak Island with its adjacent waters was made a reservation by presidential proclamation in 1892, primarily for fishery purposes. For 20 years commercial fishing was forbidden, but in March, 1912, the reservation was opened to commercial fishing by the natives and whites married to native women, who were making their homes on Afognak and Spruce Islands at that time. During these intervening years, commercial fishing was not entirely discontinued, although by the terms of the proclamation it was prohibited. No record of catches made in that period was obtainable, except in 1909 for Little Afognak Bay and in 1910 for Izhut Bay. It was known, however, that the Alaska Commercial Co., through its Kodiak station, operated a saltery at Izhut Bay before 1912 and took salmon from other Afognak streams several years before the reservation was opened. Except as already noted, these catches were either not reported or were shown as coming from other localities.

The eruption of Katmai Volcano in 1912 affected the runs of salmon in this district, as it did in the districts which include the north and northwest shores of Kodiak and Afognak Islands. The catches in that year, and several subsequent seasons, are not a true index of the productivity of the streams of this district. Runs were erratic and fishing was spasmodic; and to these conditions may be due in large part the very noticeable fluctuations in catches at the different localities in that period.

Afognak Bay was not opened to commercial fishing in 1912, but in 1918 restrictions in respect to cohos were removed, and since then fishing for that species has been permitted each year. Small catches of cohos at Katanie in 1920 and 1924 and at Markwa Bay in 1922 are included in the Afognak Bay catch for those years.

Danger Bay and Doctor Bay are producers of pink salmon chiefly, and in both localities there is a marked decline in the catch, which appears to be evidence of depletion.

Little Afognak has been a consistently fair producer of coho and red salmon, and in two years good catches of pink were made. The catch of red salmon in 1927, however, dropped to the lowest point it has reached in the recorded history of the fishery, only 159 fish being taken, and it would appear that this run is almost destroyed.

The situation at Izhut Bay, which is primarily a producer of red salmon, is essentially the same. In 18 years, from 1910 to 1927, 4 years were without recorded catch and in 3 the catch was less than 600 red salmon, 1926 and 1927 being among these. The future of this fishery is uncertain, as it seems possible that the run may not survive commercially.

Kizhuyak Bay has interesting peculiarities, in that prior to 1912 only coho and red salmon were reported as coming from that locality. In the 12 years 1911 to 1922 not a coho was taken and the catch of reds dropped from 23,341 in 1912 to an average of only a few hundred in recent years. Another peculiarity about Kizhuyak Bay is that no pinks were reported taken there until about 1911. Since then, however, pinks have constituted a large percentage of the total catch. What was once a red and coho stream has become, therefore, almost exclusively a producer of pink and chum salmon.

New localities of promise in this district are Anton Bay and Camel Rock, both of which yielded a fair number of pinks in 1927.

The district as a whole shows a precarious condition in respect to red salmon, a downward trend in production of cohos, and a definite increase in the catch of pinks and, to a lesser extent, of chums. Fishing is much more intensive than it was 10 years ago, owing to the opening of four new canneries in the district, and the fishing grounds are, with few exceptions, in quiet harbors, so that the runs of salmon are pursued more zealously and successfully than may be considered in keeping with their conservation. The fisheries here are quite local in their nature and apparently do not draw to any appreciable extent upon passing runs. This feature makes it quite probable that such intensive fishing as is now being conducted may be followed by depletion.

EAST COAST OF KODIAK ISLAND DISTRICT

The east coast of Kodiak Island district embraces the coastal waters of the east, south, and west shores of Spruce Island and of the east shore of Kodiak Island from Uzinki Narrows on the north to Cape Trinity on the south, including all adjacent islands. It has no outstanding fishery such as is found on the west coast of the island. It has, however, four localities that may be regarded as fairly important, although the runs of salmon are subject to considerable fluctuation without apparent relation to the life cycle of the different species. They are Chiniak Bay and its arms, Ugak Bay, Kiliuda Bay, and Sitkalidak Strait.

During the summer of 1888 the steamer *Albatross*, while engaged in explorations off the coast of Alaska, visited all the larger bays indenting the eastern shore of Kodiak Island and inquiries were made concerning the salmon fisheries in many localities.[15] It was learned that good runs occurred at Three Saints Bay, at Old Harbor in Sitkalidak Strait, and at Port Hobron on the north coast of Sitkalidak Island, but no mention was made of the kind or quantity of salmon obtainable in these localities. It was also reported that a saltery was in operation at Port Hobron in 1888, and that at the time of the visit of the *Albatross* party 400 barrels had been packed. No other statistical data concerning this entire district appear in the reports of the *Albatross* investigations in 1888 or 1890.

Table 22 gives the salmon catches in this district from 1894 to 1927.

Uzinki Bay, the body of water separating Spruce Island from Kodiak Island, at the head of which is located the village of Uzinki, has been a small producer of all species of salmon. The first recorded catch was 33 cohos in 1914. Beginning in 1915, the fishing resulted in a catch of 2,461 pinks, to be followed in other years by larger catches until the maximum of 35,061 was reached in 1924. Thereafter the decline was rapid, as the catch almost reached the vanishing point in 1927—only 340 pinks being caught that year. It is not known to what extent this decline was due to decreased fishing effort or to a real scarcity of salmon, but with two canneries now located at Uzinki it would be logical to expect the fishing effort to increase. It is known, of course, that the streams tributary to Uzinki Bay are few and very small. The largest one empties at the village and drains the north end of Spruce Island, while none of any consequence comes from the Kodiak side of the bay. Although considerable catches have been made occasionally in these waters it is not likely that they were taken from runs to local streams, but rather that they came from runs passing through Uzinki Bay and Narrows to other districts.

TABLE 22.—*Salmon catch and fishing appliances used in the east coast of Kodiak Island district, 1894 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Barling Bay:												
1926	1,181	13,113	74,988	3	213	-------	-------	-------	-------	-------	-------	-------
1927	-------	50	3,842	-------	-------	-------	-------	-------	-------	-------	-------	-------
Buskin River:												
1907	8,334	-------	-------	-------	6,146	-------	-------	-------	-------	-------	-------	-------
1909	4,411	-------	-------	-------	5,554	-------	-------	-------	-------	-------	-------	-------
1910	2,777	-------	-------	-------	14,336	-------	-------	-------	-------	-------	-------	-------
1911	4,138	-------	-------	-------	2,966	-------	-------	-------	-------	-------	-------	-------
1913	-------	-------	387	50	154	-------	-------	-------	-------	-------	-------	-------
1922	-------	-------	35,765	-------	350	-------	-------	-------	-------	-------	-------	-------
1923	-------	51	72,509	-------	2,736	-------	-------	-------	-------	-------	-------	-------
1924	494	-------	11,775	-------	926	-------	-------	-------	-------	-------	-------	-------
1925	2,500	11	45,814	-------	4,542	-------	-------	-------	-------	-------	-------	-------
1926	11,047	7,173	73,520	19	1,312	-------	-------	-------	-------	-------	-------	-------
1927	159	815	4,629	-------	397	-------	-------	-------	-------	-------	-------	-------
Chiniak Bay:												
1908	3,037	-------	25,926	-------	11,997	-------	-------	-------	-------	-------	-------	-------
1927	-------	22	2,212	-------	3,015	-------	-------	-------	-------	-------	-------	-------
Kaguyak Bay:												
1896	-------	-------	-------	-------	4,160	-------	-------	-------	-------	-------	-------	-------
1915	-------	-------	-------	-------	1,152	-------	-------	-------	-------	-------	-------	-------
1924	3,121	1,139	9,218	-------	753	-------	-------	-------	-------	-------	-------	-------
1926	2,425	-------	375	-------	3,543	-------	-------	-------	-------	-------	-------	-------
1927	1,478	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Kalsin Bay:												
1911	2,133	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1919	-------	-------	44,581	-------	-------	-------	-------	-------	-------	-------	-------	-------
1922	-------	-------	76,864	-------	-------	-------	-------	-------	-------	-------	-------	-------
1923	-------	-------	8,433	-------	-------	-------	-------	-------	-------	-------	-------	-------
1924	-------	-------	16,435	-------	-------	-------	-------	-------	-------	-------	-------	-------
1925	-------	-------	146,112	1	1	-------	-------	-------	-------	-------	-------	-------
1926	-------	-------	40,140	-------	-------	-------	-------	-------	-------	-------	-------	-------
1927	-------	7	22,742	-------	-------	-------	-------	-------	-------	-------	-------	-------

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[15] Explorations of the Fishing Grounds of Alaska, Washington Territory, and Oregon during 1888 by the U. S. Fish Commission steamer *Albatross*. By Z. L. Tanner and others. Bulletin, U. S. Fish Commission for 1888, Vol. VIII, 1890. Washington.

TABLE 22.—*Salmon catch and fishing appliances used in the east coast of Kodiak Island district, 1894 to 1927*—Continued

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Kiliuda Bay:												
1900					4, 900							
1912			46, 319		12, 810							
1913			58, 614		22, 473							
1914		574	36, 952	130	15, 247							
1915		777	32, 812		12, 850							
1916	14	718	228, 948	13	10, 022							
1917	720	1, 754	8, 434	41	5, 558							
1918		1, 420	53, 245	35	4, 579							
1919	47	5, 695	32, 308	274	9, 557							
1920		117	101, 881		16, 620							
1921					11, 200							
1922	192	1, 579	42, 975		17, 276							
1923	392	304	14, 487	61	11, 870							
1924	4, 006	13, 021	538, 281	20	9, 979							
1925	58	27, 802	438, 421		878							
1926	7, 198	9, 808	164, 034		1, 109							
1927	808	9, 251	288, 536		27							
Middle Bay:												
1924			14, 914									
1925		5	86, 730	1	157							
Monks Bay:												
1922			491									
1924	569											
1925	344											
1926	1, 321				5							
1927	203				2							
Russian Harbor:												
1925					1, 873							
1927	1, 336											
Shearwater Bay:												
1926	3		14, 846		5							
1927			24, 655									
Sitkalidak Strait:												
1917	926	446										
1918		1, 638	148, 916									
1919		4, 383	30, 881									
1920	70	8, 462	204, 169									
1922	12, 190	73, 952	286, 313	11	6, 070							
1923	19	8, 089	222, 083		618							
1924	96	1, 610	76, 200	112	820							
1925	4, 477	25, 464	317, 293	16	4, 576							
1926	12, 396	45, 976	234, 569	4	1, 564							
1927	6, 152	13, 010	415, 376	29	1, 379							
St. Paul Harbor:												
1920			108, 426		50							
1921			22, 257		283							
Sycamore Bay:												
1922			11, 175									
1923					2, 650							
1925		1	9, 173		1							
Ugak Bay:												
1894					120, 000							
1897					36, 960							
1900					4, 000							
1907					25, 640							
1908	7, 225				26, 703							
1909	6, 780		15, 380		55, 200							
1910			37, 679		55, 814							
1911					32, 621							
1912	357		18, 109		32, 261							
1913	2, 262		34, 043		31, 183							
1914	2, 226		17, 913	163	89, 245							
1915	2, 319		21, 602	147	27, 886							
1916	3, 225	52	117, 885	373	5, 357							
1917	127		8, 871	552	7, 396							
1919		214	18, 584	80	4, 841							
1920			15, 427		9, 266							
1921					31, 275							
1922	178	62	52, 924		7, 983							
1923	517	8	557		16, 583							
1924		7	8, 288	48	20, 535							
1925			6, 643	721	12, 162							
1926			58, 094	284	4, 045							
1927			78	97	2, 112							
Uzinki Bay:												
1914	33											
1915			2, 461									
1916	215		8, 254									
1917			11, 204									
1918			13, 546									
1919		776	7, 619									
1920	1, 864	4	25, 879									
1922		34	7, 014									
1923	405	47	6, 657		233							
1924	1, 689	45	35, 061	15	371							
1925	97	285	18, 566	1	20							
1926	2, 512	886	7, 323		198							
1927	444	59	340		6							

TABLE 22.—*Salmon catch and fishing appliances used in the east coast of Kodiak Island district, 1894 to 1927*—Continued

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
Womens Bay:												
1911	2,259											
1912	1,017		11,306		378							
1913			80,546		49							
1914			2,632		46							
1915		59			1,172							
1916			2,506		1,540							
1917			5,974									
1918		163	34,093									
1919			6,978									
1922	924		37,934									
1923	263		305		2							
1926	1,330		26,905		652							
1927		778	52,157	1								
Unallocated:												
1908	12,000				70,705							
1910			16,141									
1911	319											
1915	50		3,009		192							
1918		570	74,400									
1925		10	296									
1926				7								
Total:												
1894					120,000							
1896					4,160							
1897					36,960							
1900					8,900							
1907	8,334				31,786	12	590					
1908	22,262		35,926		109,405	11	640					
1909	11,191		15,380		60,754	20	2,140					
1910	2,777		53,820		70,150	18	2,150					
1911	8,849				35,587	10	1,375					
1912	1,374		75,734		45,449	9	905			5	300	
1913	2,262		173,590	50	53,859	9	900	1	100	6	400	
1914	2,259	574	57,497	293	104,538	7	900			6	400	
1915	2,369	836	59,884	147	43,252	6	1,010			7	515	
1916	3,454	770	357,593	386	16,919	2	400			6	420	
1917	1,773	2,200	34,483	593	12,954	7	1,000			8	560	
1918		3,791	324,200	35	4,579	10	1,040	2	400	8	360	
1919	47	11,068	140,951	354	14,398	7	900	1	250	10	600	
1920	1,934	8,583	455,782		25,936	8	1,000	1	200	12	720	1
1921			22,257		42,758	12	1,570	1	200	16	810	
1922	13,484	75,627	551,455	11	31,679	21	3,000	1	200	31	2,360	1
1923	1,596	8,499	325,031	61	34,692	18	2,275			11	650	1
1924	9,975	15,822	710,172	195	33,384	13	1,775			2	150	2
1925	7,476	53,578	1,069,048	740	24,210	21	2,425			2	150	3
1926	39,413	76,956	694,794	317	12,646	20	2,405			7	400	4
1927	10,580	23,982	814,567	129	6.938	11	1,450			8	528	3
Chiniak Bay, total:												
1907	8,334				6,146							
1908	3,037		25,926		11,997							
1909	4,411				5,554							
1910	2,777				14,336							
1911	8,530				2,966							
1912	1,017		11,306		378							
1913			80,933	50	203							
1914			2,652		46							
1915		59			1,172							
1916			2,506		1,540							
1917			5,974									
1918		163	34,093									
1919			51,559									
1920			108,426		50							
1921			22,257		283							
1922	924		150,563		350							
1923	263	51	81,247		2,738							
1924	494		43,124		926							
1925	2,500	16	278,656	2	4,700							
1926	12,377	7,173	140,565									
1927	159	1,622	81,740	3	3,412							

NOTE.—No catch reported in the years not shown in any section of this table. Catches at Newman Bay and Three Saints Bay are added to catch at Sitkalidak Strait; catches at Eagle Harbor and Portage Bay are counted as Ugak Bay salmon; catch at Nelsons Cove is counted as Uzinki Bay salmon. The unallocated catches were taken at the following places: Gibson Bay in 1911 and 1926; Humpback Bay in 1915; Kasakofsky Bay in 1908; Kodiak in 1908, 1910, and 1918; Shafka Cove in 1911; and Soldiers River in 1925.

Monks Bay, on the southern shore of Spruce Island, has produced a few salmon in recent years, mostly cohos. The stream is small and has no present or potential importance.

Sycamore Bay, or Matanaska Bay as it is known locally, indents the northeast shore of Kodiak Island about midway between Kodiak and Uzinki. It is shown as a producer of a few thousand pink salmon in 1922 and 1925, and 2,650 red salmon in 1923. This reported catch of red salmon is open to question, or else the movement of salmon in that year was most peculiar. Aside from one red taken in 1925, none was caught in this bay before or after 1923. This supports the view that the catch of that year was probably erroneously shown as Sycamore Bay fish. The streams at the head of the bay are small, yet appear to be large enough to support a much larger run of pinks, cohos, and chums than has been reported.

Chiniak Bay includes Buskin River, Kalsin Bay, Middle Bay, Womens Bay (sometimes called English Bay), and St. Paul Harbor. It is largely a producer of pink salmon, the catches of this species being exceeded in only two other localities on the east coast of Kodiak Island—Kiliuda Bay and Sitkalidak Strait. It is interesting to note that the fisheries in these localities have shown their greatest development within the last 10 years.

The red-salmon catches in this locality have been very uncertain, never large, and frequently none at all, but such as they were the greater part was taken at Buskin River. In late years this locality has produced noticeably fewer red salmon than it did 15 years earlier. There was a period of extremely unproductive years from 1912 to 1922, three of which show no catch. This total absence of red salmon may have been due to the smothering of any spawn deposited in Buskin Lake and tributaries in 1912 and the next two years, on account of the heavy fall of volcanic ash in that region which seriously affected the spawning grounds of red salmon. Since 1922 there has been a distinct increase in the catch. Buskin River has also been the chief producer of coho salmon in this locality and the fluctuation in catch is strikingly similar to that of reds, though there were nine wholly unproductive years from 1913 to 1921, inclusive.

No pinks were reported from Kalsin Bay before 1919, none from Middle Bay until 1924, and none from St. Paul Harbor (known also as the village of Kodiak) before 1920, when 108,426 were credited to that place. A small stream enters the bay at this point, which in some years has attracted a few salmon, but the probability is remote that this catch was taken entirely at St. Paul Harbor. More than likely the greater part of it came from other points on the bay.

The final section of the statistical table for the east coast of Kodiak Island district shows the total catch of salmon in the Chiniak Bay area, which is a combination of catches at St. Paul Harbor, Buskin River, Womens Bay, Middle Bay, Kalsin Bay, and Chiniak Bay. The catches of reds and cohos come chiefly from Buskin River and have been discussed above. The catches of pinks in the whole Chiniak Bay area from 1912 to 1927 are shown graphically in Table 23. There has been a remarkable increase in the catches since 1916, which is doubtless due to increased activity. It is interesting to note that there is no definite 2-year cycle established and that the fluctuations while marked are irregular. This condition has been mentioned above in the discussion of the pink-salmon runs of Afognak Island and Marmot Bay.

The earliest recorded catch of salmon along the east coast of Kodiak Island was at Eagle Harbor, Ugak Bay, in 1894, when 2,000 barrels of red salmon were pickled, representing an estimated catch of 120,000 fish. Three years later a pack of 616 barrels of reds was reported, which, at an average of 60 fish per barrel, shows a catch of 37,000 fish; and in 1900, six years later, the known catch was only 4,000 reds, all of which were packed at Karluk and Uganik. Nothing more is known of operations at Ugak Bay until 1907, yet it seems likely that fishing was carried on each year through the seasons for which statistics are not available. Beginning in 1907, records are available for each year to and including 1927, except 1918, when for unknown reasons no salmon were reported from Ugak Bay. The catch of red salmon is shown graphically in Table 24. The period from 1907 to 1915 was fairly productive, but was followed by a number of years when the reported catch was negligible. Then followed a period of slightly increased productivity from 1921 to 1925, while the catches in 1926 and 1927 were again very poor. The general picture is one of marked depletion.

TABLE 23.—*Graphic table of catches of pink salmon in the Chiniak Bay area*

[Each letter represents a catch of 10,000 fish except that fractional parts of this unit catch are considered as full units]

Year	Catch
1912	CC
1913	CCCCCCCCC
1914	C
1915	
1916	C
1917	C
1918	CCCC
1919	CCCCCC
1920	CCCCCCCCCCC
1921	CCC
1922	CCCCCCCCCCCCCCCC
1923	CCCCCCCCC
1924	CCCCC
1925	CCCCCCCCCCCCCCCCCCCCCCCCCCCC
1926	CCCCCCCCCCCCCCC
1927	CCCCCCCCC

TABLE 24.—*Graphic table of catches of red salmon in the Ugak Bay area*

[Each letter represents 2,000 fish]

Year	Catch
1907	UUUUUUUUUUUUU
1908	UUUUUUUUUUUUUU
1909	UUUUUUUUUUUUUUUUUUUUUUUUUUUU
1910	UUUUUUUUUUUUUUUUUUUUUUUUUUUU
1911	UUUUUUUUUUUUUUUUU
1912	UUUUUUUUUUUUUUUUU
1913	UUUUUUUUUUUUUUUU
1914	UUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUUU
1915	UUUUUUUUUUUUUU
1916	UUU
1917	UUUU
1918	
1919	UUU
1920	UUUUU
1921	UUUUUUUUUUUUUUUU
1922	UUUU
1923	UUUUUUUUU
1924	UUUUUUUUUUU
1925	UUUUUUU
1926	UUU
1927	UU

In respect to other species taken at Ugak Bay, statistics show that since 1916 the catch of cohos has been much lower than in the earlier years. None has been reported since 1923, and it would appear that either the run has been completely destroyed or there is no fishing for this species. Pink salmon are taken at Ugak Bay in varying quantities. The largest catch on record was made in 1916 when 117,885 were taken. Since then, 1922 and 1926 were moderately good years, but in 1927 the catch was only 78. The number of king salmon taken here has been surprisingly large in some seasons, considering the size of the stream, though in many years none was taken. There is no way of accounting for these spasmodic appearances of king salmon, yet this bay alone produced 65 per cent of the entire take of kings from the east coast of Kodiak Island district. The catch of chums has always been negligible.

Shearwater Bay, an arm of Kiliuda Bay, produced a small number of pink salmon in 1926 and 1927. This locality is shown in the table, but the catches have not been included in Kiliuda Bay figures in the table nor in the discussion given below.

The first recorded catch of salmon at Kiliuda Bay was made in 1900, when 4,900 red salmon were taken and packed at the Uganik Cannery. Evidently no further commercial fishing at Kiliuda Bay was attempted until after the establishment of a cannery at Kodiak. Since then, fishing has gone on annually through 1927, the end of the period here considered. In the total production of red salmon, it is second only to Ugak Bay, whereas it leads in the number of pinks produced by reason of its earlier exploitation. Since 1918, Sitkalidak Strait has outdistanced all other localities in this district in the yield of pinks and chums. That fact may be accounted for, in part at least, by the use of traps, while in the other localities the fishing has been almost wholly by movable appliances, chiefly senies.

The trend of the red-salmon fishery at Kiliuda has been downward, as shown graphically in Table 25. If the catch of 27 reds in 1927 is a true showing of the condition of that fishery, the run is virtually extinct. However, the run has been subject to considerable fluctuation in the 16 years for which we have records, and it may be that the poor catches of 1925 to 1927 will be followed by another period of greater abundance.

Fishing at Kiliuda Bay, as at most all other localities on the east coast of Kodiak Island, until quite recent years at least, had been largely by means of beach seines. In 1927, and perhaps in the two years immediately preceding, one trap was operated in the bay, but it was not the cause of the depletion of the reds for the catch in these three years was very small. Depletion had resulted before the introduction of traps in these waters.

The larger catches of pinks and chums from 1924 to 1927 is beyond question the direct result of trap fishing. Except in 1916 and 1920, the catch had not exceeded 100,000 pinks until 1924, when more than half a million were caught, with smaller yet substantial catches in the next three years. Another singular fact in this connection is that these salmon do not run alternately heavy and light in the even and odd years. The odd years are as productive as even years at Kiliuda Bay, and in this respect resemble the runs of Afognak Island.

TABLE 25.—*Graphic table of catches of red salmon in Kiliuda Bay*

[Each letter represents 1,000 fish]

Year	Catch
1912	KKKKKKKKKKKKK
1913	KKKKKKKKKKKKKKKKKKKKKKK
1914	KKKKKKKKKKKKKKKK
1915	KKKKKKKKKKK
1917	KKKKKK
1918	KKKKK
1919	KKKKKKKKKK
1920	KKKKKKKKKKKKKKKKK
1921	KKKKKKKKKKKK
1922	KKKKKKKKKKKKKKKKKK
1923	KKKKKKKKKKKK
1924	KKKKKKKKKK
1925	K
1926	KK
1927	K

Sitkalidak Strait embraces a fishing area of more recent development than any other in this district, and it has become an outstanding producer of pink salmon, due chiefly to the introduction of traps. The first recorded catch of salmon in these waters was in 1917, when 926 cohos and 446 chums were taken. Beginning in 1918 with a catch of 148,916 pink salmon, the catch of that species has been consistently high. Omitting 1921, when no fishing was done, it has fallen below 200,000 only twice—in 1919 and 1924—while in 1927 it reached the surprising total of 415,376. The development of this fishery is shown graphically in Table 26. Barling Bay, lately so named, is tributary to Sitkalidak Strait, and its yield of salmon rightly should be considered as a part of the Sitkalidak Strait catch, but it is shown separately in the table for future consideration in event a fishery of larger proportions develops at that point. By adding the Barling Bay catch in 1926 to the Sitkalidak Strait catch for that year, we have a total of 309,557, which is only 7,736 below the catch in 1925. It is apparent that here also, as elsewhere in the east coast of Kodiak Island district, there is no significant difference in the productivity of odd and even years.

The Sitkalidak area contains no stream of unusual size or character which would make it more attractive to chums and pinks than the streams in other bays on this coast, but the catch with two exceptions has been consistently good. It is possible that Cook Inlet and Prince William Sound runs strike the Kodiak coast at Sitkalidak Strait and Kiliuda Bay, and are intercepted at these points, but there is no definite evidence that such is the case.

TABLE 26.—*Graphic table of catches of pink salmon in Sitkalidak Strait*

[Each letter represents 10,000 fish]

Year	Catch
1918	SSSSSSSSSSSSSSS
1919	SSSS
1920	SSSSSSSSSSSSSSSSSSSSS
1921	
1922	SSSSSSSSSSSSSSSSSSSSSSSSSSSSS
1923	SSSSSSSSSSSSSSSSSSSSSSS
1924	SSSSSSSS
1925	SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
1926	SSSSSSSSSSSSSSSSSSSSSSSS
1927	SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS

Kaguyak Bay, first fished in 1896, was abandoned until 1915, when a small catch of reds was made and was not again fished until 1924. The catches recorded as from Kaguyak probably include fish caught not only in Kaguyak Bay proper but at Kiavak and other bays between Sitkalidak Island and Kaguyak.

Considering the east coast of Kodiak Island as a whole, it is found that the catch of king salmon has been unimportant, and that those of cohos and chums have fluctuated rather widely but without showing any marked trend. The red-salmon catches, as shown graphically in Table 27, show a definite decrease which may safely be ascribed to the depletion of the small runs originating chiefly in Ugak Bay, Chiniak Bay, and Buskin River. The pink-salmon catches, however, show a definite upward trend throughout the district (see Table 28), which is due in part to the development of a trap fishery. The contrasting pictures presented by the red and pink salmon catches in this district are interesting and suggestive and are typical of a fishery in which one more valuable species is being depleted and its place taken by a less valuable species. The pink salmon show no striking difference in abundance in alternate years. In this regard they differ from the runs on the mainland and on the northern and western shores of Kodiak Island and resemble the runs on Afognak Island.

TABLE 27.—*Graphic table of catches of red salmon in the east coast of Kodiak Island district, 1907–1927*

[Each letter represents 2,500 fish]

Year	Catch
1907	RRRRRRRRRRRRR
1908	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1909	RRRRRRRRRRRRRRRRRRRRRRRRR
1910	RRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1911	RRRRRRRRRRRRRRR
1912	RRRRRRRRRRRRRRRRRRR
1913	RRRRRRRRRRRRRRRRRRRRRR
1914	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
1915	RRRRRRRRRRRRRRRRRR
1916	RRRRRRR
1917	RRRRRR
1918	RR
1919	RRRRRR
1920	RRRRRRRRRRR
1921	RRRRRRRRRRRRRRRRRR
1922	RRRRRRRRR
1923	RRRRRRRRRRRRRR
1924	RRRRRRRRRRRRRR
1925	RRRRRRRRRR
1926	RRRRRR
1927	RRR

TABLE 28.—*Graphic table of catches of pink salmon in the east coast of Kodiak Island district*

[Each letter represents 20,000 fish]

Year	Catch
1908	PP
1909	P
1910	PPP
1911	
1912	PPPP
1913	PPPPPPPPP
1914	PPP
1915	PPP
1916	PPPPPPPPPPPPPPPPPP
1917	PP
1918	PPPPPPPPPPPPPPPPP
1919	PPPPPPPP
1920	PPPPPPPPPPPPPPPPPPPPPPP
1921	PP
1922	PPPPPPPPPPPPPPPPPPPPPPPPPPPP
1923	PPPPPPPPPPPPPPPPP
1924	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
1925	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
1926	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
1927	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP

COOK INLET DISTRICT

The Cook Inlet district embraces all coastal waters inside, or northerly, of a line from Cape Douglas to Cape Elizabeth. (See fig. 9.) Except for several bays in the southern part the shore line is unusually smooth and without indentations of consequence until the inlet divides at its northern end into Turnagain Arm and Knik Arm. The shore from Anchor Point to East Foreland is abrupt and is broken only by two rivers, the Kasilof and the Kenai, both of which are the outlets of large lakes, and a few much smaller streams. From East Foreland to Point Possession, the shore is less abrupt but is strewn with bowlders. There are no important streams entering the inlet in this region. Turnagain Arm has several tributary streams, but not all of them appear to be suitable for the spawning of salmon. Knik Arm is the outlet of Knik and Matanuska Rivers, and several smaller streams, most of which produce some salmon. On the west side of the inlet from Point Mackenzie to West Foreland are found the largest rivers of the district, the Susitna and Little Susitna Rivers, and several lesser streams, among which may be named Beluga, Theodore, Chuit, and Nikolai Rivers and Three Mile Creek. The shore in this section of the inlet is low and consists of wide mud flats except in the vicinity of North Foreland. These same characteristics of shore and beach are found south of West Foreland to Harriet Point. This section also has its rivers, the larger ones being the Kustatan, Katnu, and Drift; but they are comparatively unimportant as salmon streams. The west shore from Harriet Point to Cape Douglas is broken by many small bays, but it has no salmon streams of importance and is the least productive of any section in Cook Inlet. On the east side of the inlet south of Anchor Point are also several bays, but this section is likewise a small producer of

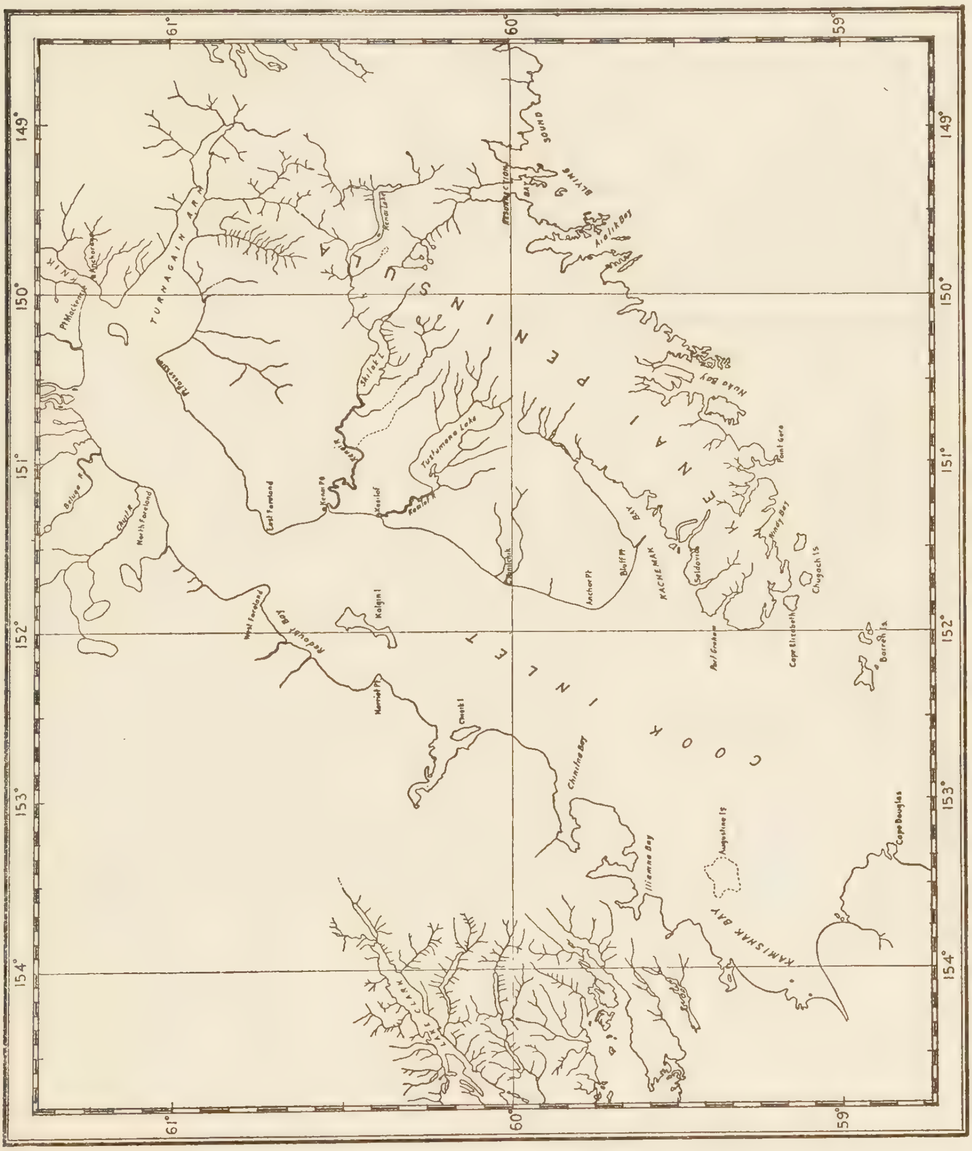
61°
60°
59°
149°
150°
151°
152°
153°
154°
KNIK
Anchorage
Pt Mackenzie
TURNAGAIN ARM
RESURRECTION BAY
SOUND
Aialik Bay
Nuka Bay
KENAI PENINSULA
Kenai Lake
Skilak L
Tustumena Lake
Kenai R
East Foreland
Kenai Pt
Kasilof
Ninilchik
Anchor Pt
Bluff Pt
KACHEMAK BAY
Seldovia
Port Graham
Cape Elizabeth
Chugach Is
Barren Is
COOK INLET
Beluga R
Chuit R
North Foreland
West Foreland
Redoubt Bay
Kalgin I
Harriet Pt
Chisik I
Chinitna Bay
Iliamna Bay
Augustine Is
KAMISHAK BAY
Cape Douglas
LAKE CLARK

FIGURE 9.—Map of Cook Inlet and Resurrection Bay

salmon as it has no large tributary streams. The Kenai and Kasilof Rivers through not the largest streams in the Cook Inlet district, are regarded as the chief producers of red salmon, and also make very material contributions toward the supply of king salmon.

The shores of Cook Inlet are washed by exceedingly strong tidal currents. The intertidal range is more than 40 feet and between East and West Foreland the currents may attain a velocity of 8 knots. Nearly all of the rivers of the district are glacier fed and carry much glacial silt into the inlet, thus making the waters north of Ninilchik exceedingly roily and ideal for gill netting, although such fishing, due to the strong currents, is not feasible. Seining is also wholly impracticable. Aside from a few set nets on the beaches, traps provide the only form of fishing appliance that can be successfully operated in these waters.

In examining the statistical reports of fishery operators on Cook Inlet, it was found that localities were occasionally given names not identifiable with any designated points on charts published by the United States Coast and Geodetic Survey and it frequently happened that names were used by the packing companies without relation to recognized geographic objects, but were adopted by the companies for their individual convenience and identification. In this way several names for approximately the same locality have come into use. In many cases the less appropriate names have been disregarded, and catches have been combined to make identity more certain. For example, Cape Kasilof, a recognized point on the east shore just south of Kasilof River, was used as a locality name by all operators taking salmon at or near the cape until 1922, and thereafter it was called "Humpy Point" by some packers and so reported by them. These catches, together with others reported from "Kasilof Highland," were combined with catches from Cape Kasilof and included under the latter name in the statistical table. Similar combinations were made in respect to other sources. Salmon reported as taken at "Moose" and "Moose Trap" were included with Moose Point fish; salmon from Ladd and Chuitna River were shown as coming from Chuit River; those from Granite Point were added to Tyonik; Snug Harbor fish were shown as coming from Tuxedni Harbor; "Kenai Beaches" salmon were included in Kenai River catches; "Corea Bend" and "Highlands" were combined with The Sisters; "Reef" with Kalifonski; "Village" with Chinilna; Homer Bay with Homer Spit; Herbert & Co., with Anchor Point. Kachemak Bay catches include salmon reported from Anesum, Aurora, "French Pete," Iverson Bros., "Manuel," and Barber Point. The data are presented in Table 29.

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
SOUTHERN PART												
Anchor Point:												
1912	6, 516	1, 771	101, 832	5, 944	74, 714							
1913	71			72	5, 589							
1914	2, 822		146, 526	1, 950	20, 448							
1917	946	303	680	443	9, 525							
1922	500	977	7, 192	504	5, 305							
1923	5, 794	39	873	2, 291	9, 513							
1926	576			1, 779	720							
1927	40	24	70	2, 000	4, 813							
Bear Cove: 1912	14	1	3, 466	10	734							
Bluff Point:												
1917	3, 000	6, 700	6, 330	955	222, 000							
1918	13, 606	17, 600	34, 830	460	174, 550							
1919	7, 000	6, 800	8, 700	300	134, 300							
1920	7, 750	6, 880	51, 100	225	131, 350							
1921	780	13, 700	2, 750	390	248, 520							
1922	11, 650	25, 730	127, 670	1, 110	69, 350							
1923	3, 326	3, 378	12, 010	516	60, 291							
1924	4, 870	3, 275	46, 190	925	80, 600							
1925	3, 540	4, 050	4, 460	2, 410	91, 170							
1926	3, 160	13, 760	61, 310	3, 940	130, 820							
1927	3, 730	14, 150	22, 390	5, 750	115, 650							
Bruin Bay:												
1919					23, 000							
1920					11, 900							
Chatham, Port:												
1922	3	378	4, 127		6							
1924		587	6, 289									
1926			1, 046									
China Poot Lagoon:												
1916	120											
1924	21		4, 496									
1925	450											
Chinilna:												
1910	1, 275		3, 500	909	53, 973							
1912	1, 000		8, 734	164	44, 016							
1913	1, 200			18	62, 536							
1921				115	8, 372							
1922	14, 151		729	515	28, 657							
1923	1, 833		1	517	29, 443							
1924	29, 156	1	34, 462	2, 345	140, 582							
Chinitna Bay: 1920		19, 500										
Clam Gulch:												
1922			929	153	8, 812							
1925	332			234	22, 025							
1926	658		4, 528	239	16, 168							
1927	630		84	996	19, 795							
Cooper Creek:												
1920	1, 250	1, 625	8, 000	95	19, 850							
1921	100	1, 200		120	40, 400							
1922	690	3, 390	9, 760	115	8, 960							
Dangerous Cape, and Russian Point: 1922					16, 100							
Deep Creek:												
1919	1, 849	33	251	151	5, 788							
1921	8	2	365	3, 024	49, 290							
1922	990		2, 600	429	8, 075							
1923	754	142		1, 645	5, 979							
1925	3, 377	177	349	4, 751	14, 925							
1926	5, 304	528	20, 554	4, 642	30, 865							
1927	540	149	410	2, 386	24, 729							
Diamond Creek:												
1919	3, 070	479	1, 471	60	31, 058							
1920	2, 379	109	4, 857	486	10, 736							
1926	840		2, 888	154	7, 601							
English Bay:												
1908	4, 320				40, 300							
1909					36, 000							
1910					37, 296							
1911	5, 190		7, 497	198	63, 750							
1912	450	425	1, 134	648	41, 302							
1913	627	83	1, 291		22, 258							
1914	150		51, 718	5, 690	26, 625							
1916					10, 528							
1917	4, 034	3, 416	4, 881	540	83, 437							
1919	843	560	1, 430	49	44, 097							
1920	2, 925	917	17, 534	178	35, 121							
1921				5	40, 282							
1922	904	472	11, 055	2	24, 396							
1923		14	20		15, 552							
1924	1, 007		33, 439		16, 539							
Flat Island:												
1917	1, 500	2, 000	4, 000	719	30, 550							
1918	7, 554	15, 230	42, 012	380	45, 018							
1919	2, 300	6, 500	8, 400	225	67, 700							
1920	11, 100	8, 325	85, 350	217	47, 450							
1921	1, 300	15, 600	1, 000	280	71, 320							
1922	3, 150	10, 550	36, 020	90	12, 670							

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
SOUTHERN PART—contd.												
Flat Island—Contd.												
1923	3, 790	2, 210	10, 230	433	20, 945							
1924	4, 690	6, 605	191, 250	515	31, 150							
1925	910	1, 960	1, 910	780	21, 520							
1926	1, 410	8, 120	35, 370	1, 720	33, 855							
1927	2, 280	5, 400	39, 030	4, 140	26, 710							
Glacier Spit: 1926			3, 206		9							
Graham, Port:												
1917		8, 000										
1919		5, 400	1, 000									
1920		6, 000	18, 640									
1922	14	418	8, 004		7							
1923		4, 811	1, 345		528							
1924		14, 429	17, 990	1	232							
1926		20, 588	2, 091		36							
1927	2, 019	6, 144	16, 913	20	2, 904							
Halibut Cove:												
1922	200		400									
1923	400		500									
Homer Spit:												
1919		769	6, 723		43							
1925	16		2	23	2, 606							
Iakaloff Bay:												
1919		1, 100										
1920		21, 000										
Kachemak Bay:												
1911	5, 428		650	64	40, 564							
1912	2, 930	462	79, 251	503	20, 354							
1913	191	23	15		1, 723							
1916	120											
1917	1, 491	3, 588	17, 828	1	10, 544							
1925			600									
1926	1, 322	9, 541	85, 055	85	9, 622							
1927	150	2, 986	101, 235		1, 927							
Kalgin Island:												
1913	15, 068		345	473	17, 377							
1914			1, 856	17	15, 706							
1916					1, 680							
1919	13, 388	87	426	419	9, 314							
1920	8, 690		3, 904	279	15, 234							
1921	1, 383	2	19	795	8, 089							
1922	24, 399	445	10, 920	134	35, 315							
1923	15, 112		38	58	27, 187							
1926	22, 384	166	5, 719	415	37, 942							
1927	46, 636	2	264	1, 030	15, 938							
Kalifonski:												
1912	549		5, 337	74	19, 561							
1913	607			338	41, 860							
1922	17, 555	323	4, 049	1, 576	50, 874							
1923	3, 257			606	29, 941							
1925	9, 510	40	22	1, 976	128, 218							
1926	16, 785	83	20, 037	1, 884	196, 285							
1927	4, 498	190	89	3, 602	133, 862							
Kamishak Bay:												
1922	170		2, 292	45	42, 965							
1923		6	8, 395		27, 435							
1924	1, 004		200		31, 194							
Kasilof Cape:												
1913	258			874	14, 700							
1914			26, 979	970	33, 895							
1919	1, 748		65	150	9, 658							
1920	11, 742	25	6, 865	1, 123	41, 336							
1921	2, 047	1, 500	71	1, 130	97, 458							
1922	9, 697	94	7, 628	831	37, 805							
1923	3, 549		52	441	36, 252							
1924	9, 130	575	21, 440	740	63, 270							
1925	8, 742	53	238	1, 473	114, 001							
1926	4, 349	210	13, 135	1, 249	86, 225							
1927	4, 734	507	1, 769	2, 287	73, 968							
Kenai River:												
1908	1, 500		6, 000	1, 922	76, 804							
1910	2, 927		5, 800	1, 243	52, 235							
1911					107, 468							
1912	1, 260		2, 414	90	5, 377							
1913				246	44, 694							
1916	100				2, 000							
1919	3, 809	57	80	431	42, 190							
1920	8, 504		6, 089	172	32, 988							
1921				862	82, 925							

Table 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
SOUTHERN PART—con.												
Koyuktolik Bay:[1]												
1916		9,000										
1917		28,000										
1919		11,500	3,000									
1920		1,851	125									
1927		854	2,444		2							
Laida Creek:												
1910	950	900	24,575	5,782	56,643							
1912	153	5,000	135,663	2,526	48,576							
1913	1,177			5,888	15,728							
1919	3,692	241	627	747	10,739							
1920	2,947	207	4,196	917	6,719							
1921	29		282	987	20,499							
Macdonald Spit: 1926			3,783									
Ninilchik:												
1914			24,787	1,447	19,259							
1917	522	131	536	2,456	29,965							
1922	5,320	2,684	30	667	9,702							
1924	3,997			3,919	18,621							
1925	2,616	116	387	698	25,012							
1926	4,938	299	10,570	3,797	52,212							
1927	382	45	42	3,182	32,041							
Porcupine:												
1913				58	1,678							
1921			10	478	15,276							
1923	3,926	21	194	586	21,114							
1925	2,617	36	146	1,118	37,635							
1926	2,394	41	7,254	680	38,460							
1927	2,210		596	1,786	35,309							
Rocky Point:												
1910				944	16,540							
1913				76	53,680							
1921	32		28	750	7,566							
1922	28		71	320	4,583							
1923	8,576	11	83	3,318	49,513							
Salamato:												
1912			178	274	35,386							
1913	295			481	107,373							
1917	3,296	5	235	181	119,118							
1918					107,785							
1919	1,000				25,000							
1920	700		2,900		49,600							
1921	4,200	5,400	9	107	66,450							
1922	7,349	64	4,558	617	43,902							
1923	10,231	200	1,163	727	79,451							
1914	21,531	261	23,279	1,021	70,955							
1925	13,244	68	530	1,748	141,820							
1926	18,257	437	24,996	1,983	188,679							
1927	17,152	720	977	3,494	119,727							
Seldovia Bay:												
1922	3	31	11,514		2							
1924	20	1,351	43,566		1							
1925		1,000	600		20							
1926		6	7,207									
Sisters, The:												
1910	1,100		11,625	414	28,879							
1912	1,079		126,865	876	53,611							
1913	5,038			4,436	90,529							
1919	5,249	101	266	888	24,523							
1920	7,442	116	7,645	3,514	42,583							
1921	1		102	546	59,119							
1922	14,425	5	17,964	3,572	99,498							
1923	7,968		134	3,455	123,493							
1924	30,670	1,807	60,720	6,309	266,566							
1925	9,377	91	405	4,634	104,183							
1926	18,427	859	53,604	3,614	215,592							
1927	7,580	650	2,707	7,839	163,594							
Starichkof:												
1912		3,190	88,934	1,262	46,004							
1913	1,944			3,008	21,477							
1917	40	211	1,948	2,254	29,961							
1919	1,873	200	582	258	14,099							
1920	3,271	103	3,913	555	6,709							
1922				1,194								
1923	6,849	139	1,513	1,092	11,312							
1926	1,586		13,283	4,509	14,631							
1927	1,460	30	700	5,422	9,994							
Tutka Bay: 1926			8,422									

[1] Koyuktolik Bay is known locally as Dogfish Bay.

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
SOUTHERN PART—con.												
Tuxedni Harbor:												
1917					5,000							
1919	2,111	7,899	529	199	7,700							
1922	7,151	15,000	75	350	3,200							
1926	765	10,659		456	4,102							
1927	2,987	6,850	1,755	1,236	5,302							
Waterfalls:												
1921			65	396	20,821							
1922	7,333		7,578	772	33,775							
1923	4,885	43	315	1,097	40,029							
1925	4,809	30	222	1,178	40,785							
1926	1,769	412	4,267	1,032	44,390							
1927	2,733	13	367	1,998	34,956							
NORTHERN PART												
Bear Trap:												
1921				858	19,861							
1922	7,282		1,132	1,244	37,517							
1923	3,523	44	110	888	20,422							
1925	5,131		255	1,171	68,285							
1926	6,326	18	6,655	769	55,118							
1927	2,892	64	98	1,015	37,996							
Beluga River: 1920	1,200		18,507		33,664							
Boulder Point:												
1917	29		13	186	14,237							
1922	778	42	2,338	9	20,852							
1923	981	24	15	134	52,068							
1924			18,635		46,555							
1925				16	21,982							
1926	4,781	209	4,395	68	85,736							
1927	805	111	4	117	34,218							
Cairn Point: 1917	68	13			2,945							
Chuit River:												
1912				1,800								
1922		6,194	159,182		24,689							
1923	3,503	2,436	595	125	22,915							
1925	8,344	1,174		700	16,688							
Cottonwood: 1927	14,874	2,361	17	2,006	9,813							
East Foreland:												
1916	800				6,000							
1922	585	3	1,086	203	18,865							
1923	522	7	7	60	16,276							
1924	4,101	277	1,565	689	17,938							
1926	1,323	21	190	37	15,204							
Goose Bay: 1917	2	2	2		9,145							
Kustatan:[2]												
1910				3,158	854							
1911				12,152								
1912				5,017								
1913				3,949	2,429							
1914				4,289	542							
1916		700										
1919	9,605	120	120	772	9,280							
1920	6,854		5,607	833	23,888							
1922	26,352	399	15,624	8,798	21,611							
1923	15,561	62	336	4,266	49,632							
1924	8,358	168	5,009	10	11,761							
1926	24,269	1,001	10,429	767	53,539							
1927	49,380	3,048	61	8,306	37,426							
McKinley:												
1924	11,791	200	13,223	41	59,052							
1925	2,963			142	33,444							
1926	10,223	289	7,297	326	48,372							
1927	6,275	376		60	15,169							
Mackenzie, Point: 1917		18			2,515							
Moose Point:												
1917	345	26	2	216	4,852							
1921	47	5	14	2,008	70,236							
1922	7,248		20,485	1,441	56,942							
1923	2,186	87	197	360	32,446							
1925	7,558	89	612	766	67,546							
1926	9,911	1,114	8,634	831	74,971							
1927	24,309	31	24	1,159	43,579							
Nikishka:												
1910	300		500	840	18,199							
1912	250		7,446	3	18,909							
1913				676	51,806							
1917	125		2	3	5,761							
1919	892	186	829	76	19,618							
1920	10,819		6,929	28	29,805							
1922	448	1,509	21,129	396	26,133							

[2] Kustatan includes 12,152 red salmon reported from Kustatan and Tyonic in 1911.

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
NORTHERN PART—con.												
Nikishka—Continued.												
1923	5,169	169	574	352	65,797							
1925	6,103	48	48	446	58,293							
1926	4,080	570	8,233	524	81,925							
1927	10,364	862	982	1,545	62,265							
Nikolai River: 1927	3,476	2		266	3,158							
Possession, Point:												
1913					18,092							
1917	212	186	33	1,620	13,622							
1921			2	357	8,368							
1922	18,010	728	39,585	865	53,087							
1923	2,031	219	163	345	26,599							
1924	14,422	3,340	71,982	750	67,937							
1925	7,909	360	295	453	41,546							
1926	6,011	2,348	9,574	442	35,596							
1927	9,167	652	50	1,013	24,490							
Swanson Creek:												
1917	4	5	14	193	4,367							
1927	2,263	26	13	61	6,171							
Three-Mile Creek:												
1917	1,452	10,917	44	4,497	37,814							
1922	6,006	2,654	75,042		14,409							
1923	4,245	2,283		12	10,829							
1924	3,570	3,726	85,170	3,168	24,179							
1926	9,084	1,384	7,110	17	12,035							
1927	15,454	1,381	11	1,322	9,706							
Trading Bay:												
1925	3,630	274	8	2,250	4,770							
1927	24,108	3,547		97	18,101							
Tyonek:												
1910				1,910	590							
1911				2,000								
1912				3,073								
1913				4,588	113							
1914				7,748	4,410							
1917	1,000	4,500		8,728	24,822							
1919	6,717	1,434	81	1	6,324							
1922	3,077	2,060	20,527	2,464	6,420							
1923	10,116	235	26	3,012	22,057							
1924	11,491	108	20,676	1,623	13,755							
1925	24,792	1,918		1,722	49,588							
1927	23,507	5,338		2,941	18,947							
West Foreland:												
1924	18,391	45	11,205	4,673	28,935							
1927	21,354	398		889	10,680							
Woronzof, Point: 1917	179	229			11,840							
Unallocated:												
1893	34,000			30,000	170,000							
1894	19,000			15,500	406,840							
1895				25,199	324,277							
1896	27,600		37,800	18,076	309,863							
1897	28,000			14,083	354,800							
1898	83,412			16,389	551,168							
1899	54,890			17,102	558,529							
1900	20,000			26,693	585,309							
1901	8,967		5,591	34,319	482,406							
1902	54,864		79,246	49,013	710,280							
1903	58,968			66,023	564,189							
1904	23,800			30,073	17,668							
1905				17,668	95,547							
1906	93,485		64,160	22,420	225,506							
1907	177,276		6,420	62,944	460,620							
1908	89,116		369,140	31,852	553,670							
1909	88,350		3,740	59,624	546,562							
1910	73,150	418	171,666	33,828	574,878							
1911	74,626	671	62,262	41,391	1,035,032							
1912	54,001	110,057	1,100,270	24,792	770,124							
1913	52,643	10,452	9,275	38,471	793,697							
1914	181,763	39,905	1,000,984	25,243	1,346,444							
1915	114,148	27,833	18,508	83,763	1,851,034							
1916	204,538	118,622	1,168,672	62,895	1,676,775							
1917	39,143	10,084	17,107	42,462	958,837							
1918	218,861	69,907	639,401	34,027	1,301,371							
1919	82,770	9,423	3,234	18,686	432.573							
1920	195,685	30,804	192,822	30,602	752,149							
1921	3,000	5,000		700	24,000							
1922	2,572	239	6,110	2,614	23,381							
1923	14,833	6,901	257	3.567	174,706							
1924	5,136		41,230	226	51,284							
1925	72,162	3,580	739	22,344	404,796							
1926	165,093	45,583	131,055	39,661	407,795							
1927	70,685	2,469	58,764	19,439	303,607							

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
NORTHERN PART—con.												
Total:												
1893	34,000	------	------	30,000	170,000	------	------	------	------	------	------	------
1894	19,000	------	------	15,500	406,840	------	------	------	------	------	------	------
1895	------	------	------	25,199	324,277	------	------	------	------	------	------	------
1896	27,600	------	37,800	18,076	309,863	------	------	------	------	------	------	------
1897	28,000	------	------	14,083	354,800	------	------	------	------	30	------	8
1898	83,412	------	------	16,389	551,168	1	------	------	------	50	------	8
1899	54,890	------	------	17,102	558,529	1	------	------	------	50	------	8
1900	20,000	------	------	26,683	585,309	1	------	------	------	57	------	13
1901	8,967	------	5,591	34,319	482,406	1	------	------	------	65	------	13
1902	54,864	------	79,246	49,013	710,280	1	------	------	------	43	------	17
1903	58,968	------	------	66,023	564,189	1	------	------	------	35	------	17
1904	23,800	------	------	30,073	489,348	------	------	------	------	14	------	8
1905	------	------	------	17,668	95,547	------	------	------	------	20	------	9
1906	93,485	------	64,100	22,420	225,506	------	------	------	------	18	------	6
1907	177,276	------	6,420	62,944	460,620	1	150	------	------	44	1,000	9
1908	94,936	------	375,140	33,774	670,774	2	300	------	------	42	5,100	13
1909	88,350	------	3,740	59,624	582,562	4	310	------	------	31	9,300	11
1910	79,702	1,318	217,666	49,028	840,187	3	200	------	------	93	5,230	20
1911	85,244	671	70,409	55,805	1,246,814	3	464	1	250	90	5,008	22
1912	68,202	120,906	1,661,524	47,056	1,178,668	3	204	4	680	102	6,570	35
1913	79,119	10,558	10,926	63,652	1,367,339	5	644	------	------	144	7,120	44
1914	184,735	39,905	1,252,850	47,354	1,467,329	4	414	1	100	208	5,840	46
1915	114,148	27,833	18,508	83,763	1,851,034	3	70	------	------	346	10,830	55
1916	205,678	128,322	1,682,672	62,895	1,696,983	8	565	------	------	155	7,810	54
1917	57,388	78,334	53,655	65,454	1,630,857	6	380	------	------	437	14,070	65
1918	240,021	102,737	716,243	34,867	1,628,724	29	1,719	------	------	341	9,005	65
1919	147,916	52,889	37,814	23,412	917,004	2	175	------	------	245	6,375	54
1920	283,258	97,462	444,983	39,224	1,291,082	7	430	------	------	327	8,980	50
1921	12,927	42,409	4,717	13,908	958,852	3	205	------	------	110	2,750	27
1922	198,040	74,389	637,405	31,030	847,865	14	1,415	------	------	240	6,375	55
1923	142,920	23,481	39,146	29,903	1,081,725	11	1,005	1	200	192	5,844	58
1924	183,356	36,755	752,016	26,955	1,041,106	3	250	1	200	198	4,950	37
1925	198,132	15,064	11,828	51,033	1,510,858	2	95	------	------	229	3,260	55
1926	346,025	118,246	581,897	75,620	1,978,505	21	610	------	------	272	6,515	71
1927	378,674	59,380	251,866	87,404	1,456,547	2	65	------	------	357	9,125	92
Total east shore (estimated):												
1893	26,860	------	------	23,700	134,300	------	------	------	------	------	------	------
1894	15,010	------	------	12,245	321,404	------	------	------	------	------	------	------
1895	------	------	------	19,909	256,160	------	------	------	------	------	------	------
1896	21,804	------	29,862	14,281	244,792	------	------	------	------	------	------	------
1897	22,120	------	------	11,126	280,292	------	------	------	------	30	------	8
1898	65,896	------	------	12,948	435,423	1	------	------	------	50	------	8
1899	43,364	------	------	13,511	441,238	1	------	------	------	50	------	8
1900	15,800	------	------	21,080	462,394	1	------	------	------	57	------	13
1901	7,086	------	4,418	27,112	381,101	1	------	------	------	65	------	13
1902	43,343	------	62,605	38,720	561,122	1	------	------	------	43	------	17
1903	46,585	------	------	52,158	445,710	1	------	------	------	35	------	17
1904	14,281	------	------	18,045	293,609	------	------	------	------	------	------	6
1905	------	------	------	10,602	57,329	------	------	------	------	------	------	7
1906	56,092	------	38,461	13,453	135,305	------	------	------	------	------	------	4
1907	109,366	------	3,852	38,867	280,372	------	------	------	------	------	------	8
1908	59,390	------	227,285	22,201	450,964	------	------	------	------	------	------	9
1909	53,010	------	2,245	35,775	363,938	------	------	------	------	------	------	9
1910	50,143	1,152	148,500	29,589	590,593	------	------	------	------	------	------	17
1911	64,097	404	55,770	29,580	968,858	------	------	------	------	------	------	19
1912	51,633	118,797	1,384,913	29,747	949,884	------	------	------	------	------	------	30
1913	44,537	9,002	7,364	41,130	1,058,896	------	------	------	------	------	------	35
1914	122,259	39,283	954,503	25,489	1,013,546	------	------	------	------	------	------	36
1915	69,931	22,964	14,502	6,327	1,237,029	------	------	------	------	------	------	41
1916	132,796	102,340	1,137,705	41,125	1,300,264	------	------	------	------	------	------	42
1917	42,656	60,033	48,626	37,460	1,213,901	------	------	------	------	------	------	42
1918	176,204	87,482	561,672	23,128	1,227,388	------	------	------	------	------	------	18
1919	88,357	40,036	33,458	16,513	686,354	------	------	------	------	------	------	33
1920	203,177	52,491	382,541	29,768	966,460	------	------	------	------	------	------	34
1921	8,365	37,402	4,672	7,854	813,022	------	------	------	------	------	------	21
1922	79,234	45,296	258,606	10,673	429,605	------	------	------	------	------	------	33
1923	61,954	12,043	28,188	17,795	600,143	------	------	------	------	------	------	36
1924	105,092	28,891	473,121	15,775	688,416	------	------	------	------	------	------	20
1925	74,979	8,291	10,189	26,601	840,106	------	------	------	------	------	------	31
1926	87,709	55,460	403,455	35,134	1,022,172	------	------	------	------	------	------	45
1927	75,401	33,099	243,263	55,894	963,255	------	------	------	------	------	------	57
Total west shore (estimated):												
1893	340	------	------	300	1,700	------	------	------	------	------	------	------
1894	190	------	------	155	4,068	------	------	------	------	------	------	------
1895	------	------	------	251	3,242	------	------	------	------	------	------	------
1896	276	------	378	180	3,098	------	------	------	------	------	------	------
1897	280	------	------	140	3,548	------	------	------	------	------	------	------
1898	834	------	------	163	5,511	------	------	------	------	------	------	------
1899	548	------	------	171	5,585	------	------	------	------	------	------	------
1900	200	------	------	266	5,853	------	------	------	------	------	------	------

TABLE 29.—*Salmon catch and fishing appliances used in the Cook Inlet district, 1894 to 1927*—Contd.

Year	Coho	Chum	Pink	King	Red	Beach seines		Purse seines		Gill nets		Traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
NORTHERN PART—con.												
Total west shore (estimated)—Contd.												
1901	89	------	55	343	4, 824	------	------	------	------	------	------	------
1902	548	------	792	490	7, 102	------	------	------	------	------	------	------
1903	589	------	------	660	5, 641	------	------	------	------	------	------	------
1904	1, 586	------	------	2, 004	32, 623	------	------	------	------	------	------	------
1905	------	------	------	1, 177	6, 369	------	------	------	------	------	------	------
1906	6, 232	------	4, 273	1, 494	15, 033	------	------	------	------	------	------	------
1907	8, 818	------	428	3, 096	26, 708	------	------	------	------	------	------	------
1908	5, 841	------	24, 809	956	35, 254	------	------	------	------	------	------	------
1909	5, 890	------	249	3, 975	36, 437	------	------	------	------	------	------	------
1910	4, 876	27	11, 444	2, 255	38, 325	------	------	------	------	------	------	------
1911	3, 524	44	2, 592	2, 029	46, 326	------	------	------	------	------	------	------
1912	4, 186	1, 090	92, 345	1, 483	56, 382	------	------	------	------	------	------	------
1913	18, 749	988	1, 018	3, 327	81, 460	------	------	------	------	------	------	1
1914	10, 412	103	51, 158	1, 610	86, 445	------	------	------	------	------	------	1
1915	7, 770	2, 551	1, 611	56, 951	137, 447	------	------	------	------	------	------	1
1916	6, 024	4, 913	59, 879	2, 164	69, 455	------	------	------	------	------	------	1
1917	1, 464	404	641	1, 574	40, 726	------	------	------	------	------	------	3
1918	8, 686	2, 876	25, 517	1, 178	47, 370	------	------	------	------	------	------	4
1919	18, 600	8, 331	1, 072	1, 319	56, 234	------	------	------	------	------	------	8
1920	16, 350	20, 891	11, 756	1, 477	56, 226	------	------	------	------	------	------	6
1921	1, 383	2	19	795	17, 089	------	------	------	------	------	------	3
1922	31, 831	15, 445	13, 516	544	81, 737	------	------	------	------	------	------	6
1923	21, 092	5, 449	8, 445	58	57, 234	------	------	------	------	------	------	3
1924	1, 004	------	200	------	31, 194	------	------	------	------	------	------	2
1925	4, 910	314	45	2, 670	16, 031	------	------	------	------	------	------	------
1926	23, 826	10, 825	7, 771	871	45, 217	------	------	------	------	------	------	3
1927	75, 405	10, 490	4, 954	3, 113	53, 061	------	------	------	------	------	------	5
Total northern part (estimated):												
1893	6, 800	------	------	6, 000	34, 000	------	------	------	------	------	------	------
1894	3, 800	------	------	3, 100	81, 368	------	------	------	------	------	------	------
1895	------	------	------	5, 039	64, 855	------	------	------	------	------	------	------
1896	5, 520	------	7, 560	3, 615	61, 973	------	------	------	------	------	------	------
1897	5, 600	------	------	2, 817	70, 960	------	------	------	------	------	------	------
1898	16, 682	------	------	3, 278	110, 234	------	------	------	------	------	------	------
1899	10, 978	------	------	3, 420	111, 706	------	------	------	------	------	------	------
1900	4, 000	------	------	5, 337	117, 062	------	------	------	------	------	------	------
1901	1, 792	------	1, 118	6, 864	96, 481	------	------	------	------	------	------	------
1902	10, 973	------	15, 849	9, 803	142, 056	------	------	------	------	------	------	------
1903	11, 794	------	------	13, 205	112, 838	------	------	------	------	------	------	------
1904	7, 933	------	------	10, 024	163, 116	------	------	------	------	------	------	2
1905	------	------	------	5, 889	31, 849	------	------	------	------	------	------	2
1906	31, 161	------	21, 366	7, 473	75, 168	------	------	------	------	------	------	2
1907	59, 092	------	2, 140	20, 981	153, 540	------	------	------	------	------	------	1
1908	29, 705	------	123, 046	10, 617	184, 556	------	------	------	------	------	------	2
1909	29, 450	------	1, 246	19, 874	182, 187	------	------	------	------	------	------	2
1910	24, 683	139	57, 722	17, 184	211, 269	------	------	------	------	------	------	3
1911	17, 623	223	12, 047	24, 196	231, 630	------	------	------	------	------	------	3
1912	12, 383	1, 019	184, 266	15, 826	172, 402	------	------	------	------	------	------	5
1913	15, 833	568	2, 544	19, 195	226, 983	------	------	------	------	------	------	8
1914	52, 064	519	247, 189	20, 255	367, 335	------	------	------	------	------	------	9
1915	36, 447	2, 318	2, 395	20, 485	476, 558	------	------	------	------	------	------	3
1916	66, 858	21, 069	485, 088	19, 606	327, 264	------	------	------	------	------	------	11
1917	13, 268	17, 897	4, 388	26, 420	376, 230	------	------	------	------	------	------	20
1918	55, 131	12, 379	129, 054	10, 561	353, 966	------	------	------	------	------	------	18
1919	40, 959	4, 522	3, 284	5, 580	174, 416	------	------	------	------	------	------	13
1920	63, 731	3, 080	71, 686	7, 979	268, 396	------	------	------	------	------	------	10
1921	3, 179	5, 005	26	5, 259	128, 741	------	------	------	------	------	------	3
1922	86, 975	13, 648	365, 283	19, 813	336, 523	------	------	------	------	------	------	16
1923	59, 874	5, 989	2, 513	12, 050	424, 348	------	------	------	------	------	------	19
1924	77, 260	7, 864	278, 695	11, 180	321, 661	------	------	------	------	------	------	15
1925	118, 243	6, 459	1, 594	21, 762	654, 721	------	------	------	------	------	------	24
1926	234, 490	51, 961	170, 671	39, 615	911, 116	------	------	------	------	------	------	23
1927	227, 868	15, 791	3, 649	28, 397	440, 231	------	------	------	------	------	------	30
Total Kachemak Bay:												
1911	5, 428	------	650	64	40, 564	------	------	------	------	------	------	------
1912	2, 944	463	82, 717	513	31, 088	------	------	------	------	------	------	------
1913	191	23	15	------	1, 723	------	------	------	------	------	------	------
1916	240	------	------	------	------	------	------	------	------	------	------	------
1917	1, 491	3, 588	17, 828	1	10, 544	------	------	------	------	------	------	------
1919	------	769	6, 723	------	43	------	------	------	------	------	------	------
1922	203	31	11, 914	------	2	------	------	------	------	------	------	------
1923	400	------	500	------	------	------	------	------	------	------	------	------
1924	41	1, 351	48, 062	------	1	------	------	------	------	------	------	------
1925	466	1, 000	1, 202	23	2, 626	------	------	------	------	------	------	------
1926	1, 322	9, 547	107, 673	85	9, 622	------	------	------	------	------	------	------
1927	1, 953	2, 986	101, 235	------	1, 927	------	------	------	------	------	------	------
Rocky Bay: [3] 1926	513	88	4, 140	------	------	------	------	------	------	------	------	------

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[3] Outside of Cook Inlet proper and not included in above totals.

NOTE.—No catch was reported in the years not shown in any division of this table.

The unallocated catch includes small occasional catches reported from the following sources: East Shore, Fish Creek, Knik Arm, Little Campbell Creek, McManus Beach, Urta, West Point, White Rock Beach, Polly Creek, Demetra & Co., Sawa & Co., and Portuguese Point. In addition, it includes a large part of the entire Cook Inlet catch, which was reported only as from Cook Inlet. There was no allocation at all previous to 1907 and it has not been complete even to date. The fishing in the inlet is so scattered that it may never be possible to get a complete and accurate allocation. As large as these unallocated totals are, the records do not make it possible to assign them accurately to any of the subdivisions of the district. For purposes of analysis, however, a division of such a large percentage of the total catch as is here unallocated is very desirable. It has, therefore, been necessary to make what is frankly a more or less arbitrary distribution of these unallocated catches among the three relatively distinct regions of the inlet—northern, east shore, and west shore. The total estimated catches in these three regions are given after the section of the table devoted to the Cook Inlet totals. By northern part is meant all the waters of the inlet north of a line between East and West Foreland. The southern part is south of that line and is further divided into the east shore and west shore which extend, respectively, from East Foreland and West Foreland to the southern limits of the inlet.

The allocations made have been based upon the best information available and in more recent years were in accordance with available knowledge of local conditions, particularly the location of the canneries and their known field of operation. From 1894 to 1903 one-fifth of the catch was credited to the northern part of the inlet. From 1904 to 1910, inclusive, one-third of the unallocated catch was credited to the northern part. Since 1910 it has been possible to make the allocations on the basis of local knowledge, but when this has not been sufficiently complete one-fourth of the unallocated portion has been credited to the northern part. From one-tenth to one-twentieth of the catch shown as coming from the southern part was allocated to the west shore unless it was definitely known that certain packers did not operate in those waters, and that a different division should be made.

No fixed rule could be followed in making these allocations. These arbitrary allocations are made in full realization of the fact that they are not, and indeed can not be, scientifically done and that in some quarters attempting such an adjustment will be criticised. It is unfortunate that more accurate data are not available, but that is a matter that can not be remedied at this late date. An allocation such as that here attempted is certainly desirable, and it seems rather doubtful that any future workers in this field will have access to more accurate data or that anyone will have available a better fund of local information as to conditions during the period under discussion. All the detailed information available is presented here, and those who may feel inclined to disagree with the allocations may disregard them. It is believed, however, that for the purposes of this analysis, the allocations here shown may be accepted as essentially correct.

In another section of the table is given the combined catch in Kachemak Bay, which includes Bear Cove, China Poot Lagoon, Glacier Spit, Halibut Cove, Homer Spit, MacDonald Spit, Seldovia Bay, and Tutka Bay; but exclusive of those taken at Bluff Point and Cooper Creek, two points on the north shore of Kachemak Bay where the run of salmon to the upper waters of the inlet strikes before passing north of Anchor Point.

The last division of the table shows a small catch of salmon in 1926 at Rocky Bay, a locality east of Cape Elizabeth and therefore not included in Cook Inlet catches.

Salmon canning on Cook Inlet began in 1882 and it has been continued without interruption ever since. No records are available showing the number of salmon of each species taken in the first 11 years of its history, but the pack in that period, irrespective of species, was reported by Moser [16] whose figures are accepted as the most reliable for this period, although the catch records of Murray [17] for 1893 have been used as being the first year in which catch statistics were published. A fair estimate of the number taken each year prior thereto could be made by assuming that the pack was 80 per cent red salmon, 10 per cent kings, and 10 per cent cohos. By figuring reds at 15 fish per case, kings at 3, and cohos at 9, a satisfactory estimate of the catch by species in these earlier years can be made.

Table 30 shows the total pack in cases for the first 12 years of salmon packing in this district:

TABLE 30.—*Pack of canned salmon on Cook Inlet, 1882–1893*

Year	Cases	Year	Cases	Year	Cases	Year	Cases
1882	6,044	1885	19,217	1888	42,421	1891	58,997
1883	14,818	1886	28,433	1889	50,494	1892	20,741
1884	21,141	1887	30,765	1890	28,655	1893	31,665

In the 6-year period from 1882 to 1887, 1 cannery operated on Cook Inlet; in the next 3 years 2 canneries were in operation; in 1891 there were 3; from 1892 to 1897, another period of 6 years, 1 cannery alone occupied the field. In 1898 and 1899, there were 2; in 1900 to 1902, there were 3; in 1903, the season opened with 2 canneries in operation, but 1 plant was destroyed by fire at the height of the season. From 1904 to 1909, there was no increase in the number of canneries, but 2 salteries were operated in 1907 and 1908, and 1 in 1909. In 1910, the number of canneries increased to 2, 1 more was added in 1911, 2 in 1912, bringing the number to 5. Another was added in 1915, and except for the destruction by fire of 1 plant at Kenai, which was rebuilt the following season, no change in the number of canneries occurred until 1918, when it was reduced to 5 by the permanent closing of a small plant on Goose Bay near the head of Knik Arm. Only 4 were operated in 1919, 7 in 1920, 4 in 1921, and 9 in 1922. The number decreased in the next two years and then gradually increased to 11 in 1927.

In this connection, consideration should also be given to the number of traps operated in Cook Inlet as having a direct relation to the catch and to the number of canneries. As new canneries are opened, fishing appliances are increased or a corresponding division made of the then operating equipment in order that the lately established plants may obtain a supply of fish; usually the alternative first mentioned is followed. From the beginning of canning in 1882, until the close of the season of 1896, fishing was probably limited by choice to the use of beach seines and gill nets operated in the rivers. At least no reference to the use of traps is found in any published report until 1897 when eight were installed and successfully fished. Thereafter for 13 years the number of traps used in any season did not exceed 20, and the number of canneries was not more than 3. In 1912, the number of canneries had increased to 5, the number of traps to 34, and the largest catch of salmon considering all species, was recorded although the catch of reds was about 70,000 less than in 1911. From then until 1918, there was a gradual increase in the number of traps, and the number of canneries fluctuated from five to six while the catch reached higher levels than ever before attained and was consistently well above the average of earlier years.

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[16] Alaska Salmon Investigations in 1900 and 1901, by Jefferson F. Moser. Bulletin, U. S. Fish Commission, Vol. XXI, 1901 (1902), pp. 175–398. Washington.

[17] Report of the Salmon Fisheries of Alaska, 1894, by Joseph Murray, special agent. Washington, 1896.

After 1918 there was considerable fluctuation in the number of canneries and traps operated as well as in the catch of salmon, the lowest level in years being reached in 1921, due to economic depression which affected the fisheries industry generally throughout Alaska. Recovery from this depression was rapid, however, as both canneries and traps multiplied twofold, and the highest level of production ever known in the Cook Inlet district was reached in 1926. In 1927, the number of canneries and traps was materially increased, but the catch was appreciably lower although not far below the average of the last 12 years. All of the new canneries in this district were small and their combined capacity and output would scarcely equal that of any one of the long-established plants such as are found at Port Graham, Kasilof, and Kenai. Similarly the increase in traps was due in large measure to the operation of many so-called mosquito traps which were hand driven on the mud beaches of the west shore north of West Foreland. These traps are equipped with plank floors about 3 feet above the ground and are entirely out of the water at low tide. For that reason they are not continuously fishing like the deep-water traps and their catches are relatively smaller. If all traps were of the same size and effectiveness, it would be obvious that with increase in number fishing had become more intensive; but it is apparent that in Cook Inlet the intensity of fishing has not changed proportionately with the addition of more canneries and traps.

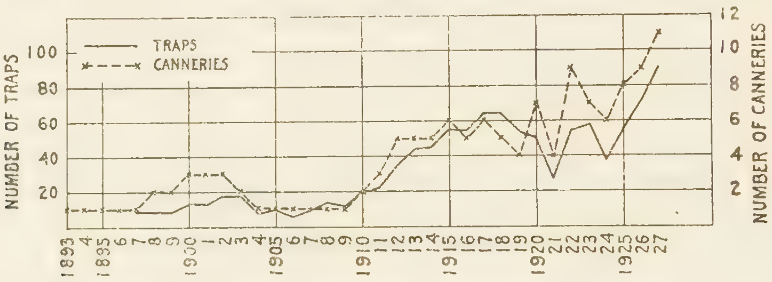

FIGURE 10.—Number of canneries and traps operated on Cook Inlet

The increase in canneries and traps is shown graphically in Figure 10.

The purpose of this brief description of the development of the salmon fisheries of Cook Inlet is to make possible a correct understanding of present conditions and the analysis of catches by species which follows. With such incomplete data to deal with it is obviously impossible to make satisfactory analysis of the catches in minor localities. It has been necessary, therefore, to consider only the larger sections and Cook Inlet as a whole.

RED SALMON

From the inception of the industry in 1882 to the present time the red salmon have constituted the main dependence of the fisheries. Beginning in 1893, when catch statistics were first available, the general trend of production has been steadily upward. (See fig. 11.) This upward trend was interrupted between 1902 and 1908, and again for a period of several years beginning in 1919. The first interruption is easily explained. Only 2 canneries of the 3 that operated in 1902 resumed packing in 1903, and at the height of the season 1 of these was destroyed by fire. The reduction in pack that followed was not, according to Kutchin [18] due to scarcity of salmon. In 1904, with only one cannery in the field, Kutchin [19] again reported that salmon were never more plentiful, and that the pack would have been larger had not the supply of tin been exhausted before the run was over. He also pointed out that this year the run at first was heaviest from the north, indicating that the salmon had held a course some distance from shore on their northward movement into the inlet and thus avoided the traps until they approached the rivers on their rush down the inlet. On July 12, 1905, the only remaining cannery on the inlet was destroyed by fire just at the beginning of what promised to be a good season. The falling off in catch from more than 700,000 in 1902 to less than 100,000 in 1905 was not due to biological causes but to the interruption of activities by disastrous fires. Recovery from this shrinkage in pack in the next 10 years was rapid and somewhat spectacular, the catch moving from the low level of 1905 to more than 1,850,000 in 1915. Three good years then followed in which the catches were only slightly below the peak of 1915. The catches for the next six years, 1919 to 1924, inclusive, were decidedly lower, a sudden drop in 1919 bringing the catch to 917,000—the lowest point production had reached in nine years. In 1920, the catch improved slightly but it again fell in 1921 to approximately 950,000, largely for economic reasons as there were fewer canneries in operation and a marked decrease in the number of traps and gill nets in use. After 1922 another upward movement began which was even more rapid than the one in 1915; it culminated in a catch of nearly 2,000,000 reds in 1926, despite the limitation of fishing season and the total prohibition of fishing in certain areas under authority conferred by the fishery law enacted in 1924. The escapement in 1926 was also reported to be exceptionally large. In 1927, the catch again approached 1,500,000, a considerable drop from the year before, but still a good year for Cook Inlet.

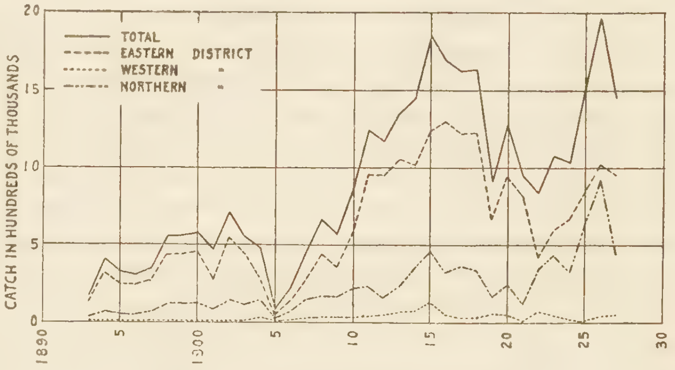

FIGURE 11.—Catch of red salmon in Cook Inlet

With all its wide expanse of water and large streams, Cook Inlet has never produced a run of salmon equal to that found in several smaller districts, such as Karluk for instance, and it seems unlikely that it will ever be a much larger producer than it is now. The red salmon run is of extremely short duration. It strikes the inlet about the middle of July and by the end of the month is practically over; the schools make rapid progress to the spawning streams, particularly those along the east shore. As a general thing, about 65 per cent of the catch is made south of

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[18] Report on the Salmon Fisheries of Alaska, 1903 (1904), by Howard M. Kutchin, Washington.

[19] Report on the Salmon Fisheries of Alaska, 1904 (1905), by Howard M. Kutchin, Washington.

East Foreland, though in a few recent seasons the district north of the Forelands produced almost half of the catch. Owing to the physical peculiarities of the inlet north of Anchor Point, where there are no bays or conspicuous indentations where fishing could be localized, it has been impracticable to attempt an allocation of the catch to particular streams, and it was necessary to adopt the names of localities used by the canning companies and show the catch at such places. By noting, for example, the catches at Bluff Point, Kalifonski, Cape Kasilof, Salamato, Nikishka, Point Possession, Deep Creek, and Clam Gulch, it might be inferred that important streams enter the inlet at these places, but such inference would be incorrect. These names and many others shown in the table are simply the designations of landmarks which bear no necessary relation to the probable destination of the salmon captured. It is quite certain, for example, that the traps at Bluff Point, or at Starichkof, take chiefly Kenai and Kasilof River fish rather than salmon bound to the streams nearest their respective locations.

Only in some of the small bays below Anchor Point where salmon were taken by seines and gill nets, can definite allocations be made. Tagging experiments conducted in 1929 showed that in the region of Flat Island the salmon taken in the commercial fishery are chiefly of local origin,[20] but at Nubble Point in Kachemak Bay the catch of red salmon evidently comes from runs that belong to streams north of Anchor Point, presumably chiefly Kenai and Kasilof Rivers. South of the Forelands the salmon runs tend to follow the east shore north of Anchor Point, but above the Forelands they are dispersed to both shores. It is also significant that traps just north of Cape Kasilof show about the same catch as the traps just south of the Forelands, indicating that a considerable part of the run stands far enough off shore in passing through the lower part of the inlet to escape the traps there. Traps near the Kenai and Kasilof Rivers appear to be relatively better producers than any others, indicating with reasonable certainty that these rivers are the more important spawning streams in the district. The fact that traps as far north as Point Possession and Moose Point make as large catches as those located at Starichkof, Ninilchik, Porcupine, and Laida Creek in the southern part of the inlet is also significant as showing that salmon were fairly abundant even at the northern limit of the waters that are now open to commercial fishing. In view of that circumstance it seems probable that there are reasonable escapements to the streams of the upper part of Cook Inlet.

The fishery along the western shore south of the Forelands obviously, has never been of great importance. Considering Cook Inlet as a whole, there is nothing to indicate depletion of the red salmon runs, though there have been rather wide fluctuations in catch in recent years. In general the catch shows no definite tendency to decrease and it does not appear probable that this is the result of a corresponding increase in the intensity of fishing. On the other hand the relatively stringent regulations that have been effective since 1924 do not seem to have affected the catch in the slightest. It is believed that Cook Inlet is decidedly limited in its productivity, and the prophesy is ventured that the district can not withstand any great increase in the exploitation of the salmon resources without grave danger of depletion.

OTHER SPECIES

Cook Inlet takes third place in the production of king salmon, being exceeded only by the catch by trollers in southeastern Alaska and the gill-net catch at Nushagak Bay in western Alaska. The history of the development of the king-salmon fishery is inseparable from that of the red salmon. Exploitation of both species began at the same time and developed simultaneously at about the same rate. Kings were as much sought after as reds; they were taken in the same localities by both traps and gill nets, but no record was made of the number taken until 1893. In the next 15 years, though catch records were kept, no allocations were made to specific streams or places; all catches were simply shown as coming from Cook Inlet. Nothing could be done, therefore, with these statistics beyond showing them as unallocated. As the industry expanded more attention was given by the operators to the furnishing of detailed information in respect to places where salmon were caught, so that in later years a more general compliance with the Government's requirements in the matter of fishery statistics resulted in well-defined allocation of catches; but even then, as in the case of the red salmon, there still remained a large unallocated catch. At first, fishing was confined to areas near the canneries; in fact much of it was done directly in the rivers on which the packing establishments were located, notably the Kasilof, Kenai, and Chuit. Both gill nets and traps were set in these streams, but in time river fishing was prohibited. Before traps became the preferred form of fishing appliance, two-thirds of the king-salmon catch was taken by gill nets. In late years, however, traps have caught far more kings than have been taken in gill nets, though the latter are used now as set nets along the west shore in the vicinity of Kustatan, Tyonek, and Ladd with very good results. In early days, drift gill netting was commonly practiced with moderate success despite the difficulties of fishing in the strong tidal currents north of Kalgin Island where this manner of fishing was employed.

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[20] Salmon Tagging Experiments in Alaska, 1929 (1930), by Seton H. Thompson.

TABLE 31.—*Graphic table showing catch of king salmon in Cook Inlet, 1893–1927*

[Each letter represents 5,000 fish]

Year	Catch
1893	XXXXXX
1894	XXX
1895	XXXXXX
1896	XXXX
1897	XXX
1898	XXXX
1899	XXXX
1900	XXXXXX
1901	XXXXXXX
1902	XXXXXXXXXX
1903	XXXXXXXXXXXXXX
1904	XXXXXXX
1905	XXXX
1906	XXXXX
1907	XXXXXXXXXXXXX
1908	XXXXXXX
1909	XXXXXXXXXXXX
1909	XXXXXXXXXXXX
1910	XXXXXXXXXX
1911	XXXXXXXXXXXX
1912	XXXXXXXXXX
1913	XXXXXXXXXXXXX
1914	XXXXXXXXXX
1915	XXXXXXXXXXXXXXXXX
1916	XXXXXXXXXXXXX
1917	XXXXXXXXXXXXXXXXX
1918	XXXXXXX
1919	XXXXX
1920	XXXXXXXX
1921	XXX
1922	XXXXXXX
1923	XXXXXX
1924	XXXXXX
1925	XXXXXXXXXXX
1926	XXXXXXXXXXXXXXXX
1927	XXXXXXXXXXXXX

Table 31 shows graphically the catch of kings from 1893 to 1927. Fluctuations at first had apparently little significance; but from the low catch of 14,083 in 1897 there was a steady rise through six years until the catch reached 66,023 in 1903, and then dropped suddenly to 17,668 in 1905 due to the loss of canneries by fire, as explained above, rather than to a scarcity of fish. As canneries were reestablished, the catch again climbed rapidly and in the next two years almost reached the high level of 1903. Then began a series of mild fluctuations which culminated in a new peak catch of 83,763 in 1915, from which another decline occurred and for a period of seven years (1918 to 1924) the catches were only about half the average catch for the preceding decade. It is interesting to note how closely these larger fluctuations in the catch of king salmon coincide with those in the catches of reds which were also greatly reduced from 1919 to 1924, inclusive. It seems quite certain that this depression was partly economic, but it is thought that kings were actually somewhat scarcer after 1917 than for several years preceding. The recovery from this period of poor catches was rapid and abrupt and it brought the catch of 1927 to the highest level ever reached in the production of king salmon in the Cook Inlet district.

Practically nothing of a biological nature is known of the Cook Inlet king salmon. Its spawning grounds are unexplored; its age at maturity is unknown, and the run in one year bears no apparent relation to that of any other year in so far as shown by the catch statistics. Until these gaps in our information are filled we can not be sure of just what is happening to the salmon runs, but from the data considered here no definite evidence is seen that the king salmon have suffered any alarming depletion in more than 40 years of uninterrupted fishing.

PINK SALMON

The supply of pink salmon in Cook Inlet has never been large if the catch may be accepted as an indication of the size of the run. Apparently no serious effort was made to take this species until after 1907. Previously the annual catch had never been more than 100,000 and in several years none was reported. Beginning in 1906, pink salmon have been taken every year, the larger catches falling in the even years, while the number taken in the odd years was invariably negligible until 1927. This oscillation in runs is clearly illustrated in Table 32. Only three times in 32 years has the catch exceeded 1,000,000, thus giving rather positive proof that the inlet is not an important producer of pink salmon. The first large catch was reported in 1912 when 1,661,524 were taken. Two years later 1,252,850 were caught and in 1916—the last of the three big years—the catch was 1,682,672. Since then it has varied between about five and seven hundred thousand. This reduced catch since 1916 is probably due to biological causes, although it may be that in later years the fishing effort has not been sustained after the runs of other species was over. The prohibition of fishing in 1924 from August 10 to the end of the year and in 1926 from August 10 to 25, may also have cut into the pink-salmon season so as to render larger packs impossible.

TABLE 32.—*Graphic table showing catch of pink salmon, Cook Inlet, 1906–1927*

[Each letter represents 50,000 fish]

Year	Catch
1906	XX
1907	X
1908	XXXXXXXX
1909	X
1910	XXXXX
1911	XX
1912	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1913	X
1914	XXXXXXXXXXXXXXXXXXXXXXXXXX
1915	X
1916	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1917	XX
1918	XXXXXXXXXXXXXXX
1919	X
1920	XXXXXXXXX
1921	X
1922	XXXXXXXXXXXXX
1923	X
1924	XXXXXXXXXXXXXXXX
1925	X
1926	XXXXXXXXXXXX
1927	XXXXXX

Pink salmon were taken in all important localities in the inlet, but the bulk of the catch was unallocated prior to 1918. In 1916 the entire catch was unallocated, and high percentages in earlier years were likewise reported as merely coming from Cook Inlet. Data for subsequent years are more definite and can be discussed with reasonable exactness. It is known that before 1921 there was comparatively little fishing for pinks south of Bluff Point, but it seems impossible to make a finer division of the unallocated catch in those earlier years beyond that shown in the three sections termed "east shore," "west shore," and "northern part." Since 1921 the catch of pinks has come chiefly from the east shore, except in three instances when noteworthy catches were made in the northern part of the inlet. One of these occurred in 1922 when 159,182 pinks were taken in the vicinity of Chuit River and the other two in 1924 at Three Mile Creek and Point Possession. Since 1924 no locality north of the Forelands has produced any considerable number of pinks. In 1926, 45 per cent of the catch, exclusive of unallocated fish, came from waters of the eastern shore south of Anchor Point; and in 1927, 94 per cent of the allocated catch, or 72 per cent of the entire inlet catch, came from the same waters, of which 55 per cent, or 101,235, came from the south shore of Kachemak Bay east of Seldovia Bay—a district that had been fished but little until recently. Nineteen hundred and twenty-seven provided the largest catch of pink salmon recorded for any odd year since fishing commenced on the inlet. This is an interesting development of the pink-salmon fishery in showing a departure from the old order of things and contrary to the well-established notion that runs of pinks are very light in the odd years. A quarter of a million salmon from a district the size of Cook Inlet is not a large catch in one season, but in comparison with the average catch in preceding off years it constitutes a change worthy of more than passing notice. It is interesting to note, however, that in various other places throughout central Alaska 1927 was an exceptionally productive odd year. Bower[21] in discussing the small pack of 1927 says: "A contributing factor also was the smaller run of humpback salmon that occurs in central Alaska in alternate years, although it may be noted that while the catch of this species was considerably less than in 1926 and 1924, it was larger than for any year prior to 1924, and far in excess of any previous off-year catch in the district." Everything indicates that the odd-year runs of pinks have suddenly built up to approximately the level of the even-year runs. If the future odd-year runs continue to improve and the even-year runs are maintained unimpaired, it will mean a large increase in the pink-salmon packs in central Alaska. The reason for this sudden development is quite unknown and will doubtless remain so, although it may be suggested that the winter of 1925–26, which followed the spawning that produced the large run of 1927, was exceptionally mild. It was a matter of common observation that this was the case, and the fact is recorded in the reports of the Weather Bureau.

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[21] Alaska Fishery and Fur-Seal Industries in 1927. By Ward T. Bower, Report U. S. Commissioner of Fisheries for 1928.

COHO SALMON

Since 1893 Cook Inlet has produced cohos in every year except 1895 and 1905. Catches were small prior to 1907, and also in the five years immediately following that season. (Table 33 shows the catches since 1906.) The exceptional catch in 1907 is unexplained in any literature on the fisheries of the inlet examined, and nothing is known of the distribution of cohos in that year, as the catch was entirely unallocated. In 1914 the catch began a fluctuating movement similar to that of pinks, with good catches made in the even years and poorer catches in the odd years. This continued until 1923, but since then the 2-year cycle has not been apparent. It is probable that these are due to some association between the fisheries for pinks and cohos. In general, the trend has been and still is upward. The poor pack in 1921 was not indicative of a scarcity of fish, but was undoubtedly owing to economic causes. In 1927 the catch reached a total of 378,674 and marked a new high level of coho production in the Cook Inlet district. It is interesting to note that 49 per cent of the allocated catch in 1926 and 62 per cent in 1927 came from localities north of East and West Foreland. In 1920 the third best year of coho production, only 21 per cent of the allocated catch came from those places. From this it would appear that cohos prefer the more northerly streams of the inlet, and that the closed season of 10 days in August has restricted the catch in waters south of the Forelands. No evidence of depletion of this species can be seen.

TABLE 33.—*Graphic table showing catch of coho salmon, Cook Inlet, 1906–1927*

[Each letter represents 10,000 fish]

Year	Catch
1906	XXXXXXXXXX
1907	XXXXXXXXXXXXXXXXXX
1908	XXXXXXXXXX
1909	XXXXXXXXX
1910	XXXXXXXX
1911	XXXXXXXXX
1912	XXXXXXX
1913	XXXXXXXX
1914	XXXXXXXXXXXXXXXXXX
1915	XXXXXXXXXXXX
1916	XXXXXXXXXXXXXXXXXXXXX
1917	XXXXXX
1918	XXXXXXXXXXXXXXXXXXXXXXXXX
1919	XXXXXXXXXXXXXXX
1920	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1921	XX
1922	XXXXXXXXXXXXXXXXXXXX
1923	XXXXXXXXXXXXXX
1924	XXXXXXXXXXXXXXXXXXX
1925	XXXXXXXXXXXXXXXXXXXX
1926	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
1927	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

CHUM SALMON

The first recorded catch of chums in Cook Inlet was made in 1910. The history since then is shown graphically in Table 34. In the first nine years, the bulk of the catch was unallocated so that consideration need be given only to the number taken annually since 1918, except to mention that in 1912 and in 1916 the catch was more than 100,000. In 1918, it again exceeded that figure, but by a very narrow margin. Larger catches in the even years were followed by smaller ones in the odd years, the peaks becoming lower and the depressions deeper until in 1925 only 15,064 were caught—the smallest production in 12 years. In 1926, the catch rose sharply to approximately 120,000, an increase not unlike those shown in the catches of cohos, kings, and reds, but it was followed by a drop to 59,380 in 1927. The marked downward trend from 1916 to 1925 might well be considered as evidence of serious depletion, were it not for the sudden increase in the catch that occurred in 1926. As it is, it is not possible to state whether this species has been reduced in abundance or not, but, in view of the fact that none of the other species show clear evidence of depletion, it seems safe to assume that the same thing is true of the chums. If the size of the run in any year is reflected in the number of chums caught, it is at once apparent that the chum resources of Cook Inlet are economically unimportant, and that all reported catches were chiefly incidental to fishing for other species. Chums coming mainly from waters of the east shore south of Anchor Point, through Chinitna Bay, Tuxedni Harbor, Tyonek, and Three Mile Creek on the west shore have produced fair quantities in a few seasons. As a whole, this fishery holds little promise of much larger development. There may be localities in which moderately good catches will continue to be made, but there is no indication that any of them will be found in the northern sections of the inlet.

TABLE 34.—*Graphic table showing catch of chum salmon, Cook Inlet, 1910 to 1927*

[Each figure represents 5,000 fish]

Year	Catch
1910	X
1911	X
1912	XXXXXXXXXXXXXXXXXXXXXXXX
1913	XXX
1914	XXXXXXXX
1915	XXXXXX
1916	XXXXXXXXXXXXXXXXXXXXXXXXX
1917	XXXXXXXXXXXXXXXX
1918	XXXXXXXXXXXXXXXXXXXXX
1919	XXXXXXXXXXX
1920	XXXXXXXXXXXXXXXXXXXX
1921	XXXXXXXXX
1922	XXXXXXXXXXXXXXX
1923	XXXXX
1924	XXXXXXXX
1925	XXX
1926	XXXXXXXXXXXXXXXXXXXXXXX
1927	XXXXXXXXXXXX

RESURRECTION BAY DISTRICT

This district embraces Resurrection Bay exclusively. The fishery districts nearest to it are Prince William Sound on the east and Cook Inlet on the west. In both directions, especially to the westward, are miles of coastal waters that have no salmon fisheries, so that this bay stands as a district wholly apart from any other, and it is quite certain that what is here shown as the catch came from runs belonging strictly to these waters. The figures are given in Table 35.

Aside from a few small precipitous streams that attract coho salmon, Resurrection Bay has three fairly large tributaries entering at its head—Resurrection River, Bear Creek, and one stream unknown by name except to local residents. These larger streams are the chief source of the salmon supply of this district. Bear Creek is undoubtedly the largest producer of red salmon, and perhaps of the other species, though Resurrection River is a much larger stream. The river is a rough, glacial stream, whereas Bear Creek is lake fed, less tumultuous, and provides larger areas for spawning beds.

In late years, fishing has been entirely with gill nets, though in the earlier history of the fishery both beach and purse seines were used and in one season a trap was driven near Kanes Head on the west side of the bay about 8 miles south of Seward, but it caught very few salmon.

TABLE 35.—*Salmon catch and fishing appliances used in the Resurrection Bay district, 1911 to 1927*

Year	Coho	Chum	Pinks	King	Red	Beach seines		Purse seines		Gill nets		Pile traps
						Number	*Fathoms*	*Number*	*Fathoms*	*Number*	*Fathoms*	*Number*
1911	2,665	78	256	40	2,340	--------	--------	1	16	2	150	--------
1912	2,365	722	350	810	16,220	--------	--------	--------	--------	7	400	--------
1913	2,365	255	--------	--------	1,857	--------	--------	--------	--------	4	200	--------
1914	3,606	--------	2,948	200	5,500	--------	--------	--------	--------	6	259	--------
1915	7,880	--------	800	30	9,650	1	125	--------	--------	14	680	--------
1916	4,300	--------	--------	--------	2,340	1	85	--------	--------	7	360	--------
1917	3,388	134	631	45	29,050	--------	--------	--------	--------	9	600	--------
1918	11,130	5,463	4,988	19	39,670	4	300	--------	--------	26	2,190	1
1919	24,939	1,444	5,633	389	26,690	--------	--------	3	420	36	2,810	--------
1920	19,095	79	541	339	23,834	--------	--------	2	190	24	1,800	--------
1921	7,592	--------	--------	38	24,773	--------	--------	1	115	15	1,050	--------
1922	1,883	--------	--------	--------	12,154	--------	--------	1	85	14	840	--------
1923	6	--------	--------	8	17,740	--------	--------	--------	--------	14	800	--------
1924	4,300	--------	--------	57	14,984	--------	--------	--------	--------	14	840	--------
1925	14	--------	--------	--------	3	--------	--------	--------	--------	--------	--------	--------
1926	6,635	121	17	--------	21,215	--------	--------	--------	--------	18	1,800	--------
1927	9,072	--------	--------	--------	2,521	--------	--------	--------	--------	14	1,120	--------

This district produces a small run of reds and cohos. All other species have been taken, but the catches were decidedly irregular. Since 1920, the catch of other species has been extremely small, and in most of the years none at all.

Efforts were made to build up a larger run here by artificial propagation and by clearing the streams of obstructions to make larger and better areas available for spawning fish, but the runs continue to be small and the possibility of developing a much larger fishery in this district than now exists seems remote.

A cannery was built at Seward in 1917 and was operated each season through 1921. These five years cover the most productive period of the Resurrection Bay salmon fisheries, and they also represent the period of most intensive fishing. Fishing in these years demonstrated conclusively that the supply of fish was insufficient for the profitable operation of a cannery, and that the runs gave little promise of ever becoming profitable.

ANNUAL GROWTH OF FRESH-WATER MUSSELS [1]

By Thomas K. Chamberlain, *Associate Aquatic Biologist*

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INTRODUCTION

In view of the progressive depletion of the natural beds of commercial fresh-water mussels used in the manufacture of pearl buttons, it has become desirable to determine the action of various factors bearing on future supplies of these shells. At present no adequate data exist on the age and growth of commercial mussels; and, consequently, little is known concerning the age at which these mussels could best be taken from the streams, considering both the economic value of the shells to the manufacturers and the interests of conservation. Accordingly a detailed study of the growth of fresh-water mussels representing four commercial North American species has been made, using the "annual ring" method as applied to mollusks by Weymouth (1923) in his work on the Pismo clam.

The determinations of the length-age relations of the upper Mississippi shells used in these studies were begun in the laboratories of physiology at Stanford University in 1926. Subsequently, additional material was measured at the United States Bureau of Fisheries Biological Station, at Fairport, Iowa. The length-age and weight-age studies of the Arkansas and Texas shells, and all of the thickness-age studies, were made in the laboratories of physiology of the University of Missouri. The writer is greatly indebted to Dr. F. W. Weymouth, of Stanford University, and to Dr. M. M. Ellis, of the University of Missouri, for their advice and suggestions in connection with this work.

METHOD

In many organisms the variations in growth rate, occurring at intervals and associated with such factors as temperature or drought, produce rings or other marks in the hard structures. The use of these records in the determination of the age of trees, where the rapid growth of summer, the slow growth of winter, and sometimes intermediate stages caused by drought or other unfavorable conditions, leave distinct rings in the cross section of the trunk, which can be recognized as belonging to known seasons of the year, first established the ring method of age determination. The accuracy of this method for trees has been demonstrated recently by the remarkable researches in the Southwest by Douglass (1929).

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[1] Approved for publication, Sept. 30, 1930.

Certain ridges, lines, or other marks appearing on or in the scales, otoliths, vertebræ, and other hard parts of fish have been determined by investigators to be of annual occurrence. Because of resemblances to the rings of growth of trees, these marks of growth in animals also have been called rings.

Gilbert (1913), Frazer (1917), Rich (1920), Creaser (1926), and others have used the rings in scales in determining the rate of growth of fish. Crozier (1914, 1918) showed that the growth lines in the shells of chiton were significant in determining age. Weymouth (1923) established the association of the rings occurring in the Pismo clam with the retardation of growth during the winter period, and McMillin (1924) made use of the rings occurring in the razor clam in determining the normal course of growth in that animal.

Hessing (1859), working with European species, was perhaps the first scientific writer to call attention to the possible correlation of certain rings in the shells of fresh-water mussels with the annual growth of these animals, although he was unable to decide definitely that these rings were of annual occurrence. Hazay (1881), following the growth of individual Hungarian mussels, found that no growth occurred during the late winter months, resulting in the formation of a definite ring in the periostracum of the shells. As there was but a single major growth period each year, Hazay's work established these rings as annual marks. Lefevre and Curtis (1912), from their studies of specimens of the North American mussel, the pocketbook, *Lampsilis ventricosa* (Barnes), which they kept under observation for three years, conclude that the rings mark the boundaries of growth periods; but since various factors may cause cessation of growth, these writers were not entirely certain that a single growth period always corresponds to a single year.

Rubbel (1913), after measuring over 300 specimens of a European fresh-water mussel, *Margaritana margaritifera* (Linnæus), which he then planted, and remeasured two years later, also felt uncertain as to the significance of these rings as marks of annual growth. Isley (1914), from his study of some 900 specimens of North American species of fresh-water mussels which he tagged and subsequently recovered, states that the winter rings, or arrested growth rings, as he recommends calling them, are usually sufficiently regular and definite to be used as indicators of age. He did not, however, make use of these rings in his own studies of the normal course of growth.

Coker, Shira, Clark, and Howard (1921) held a number of fresh-water mussels at the United States Fisheries Biological Station at Fairport, Iowa, for periods of years and measured them annually. These authors made a very careful study of the growth rings by using sections of the shell. They pointed out that the growth of the shell in length and breadth is accomplished by the secretion by the mantle of the three layers of shell substance at or near the margin of the mantle. A period of cold or any disturbance, such as handling, causes the mantle to withdraw from the margin of the shell to such an extent as to break its continuity with the thin and flexible edge of the shell. When the deposition of shell is resumed, the new layers of prismatic substance and periostracum are not continuous with the old. The amount of overlapping of layers in the region of interrupted growth appears to depend on the extent to which the mantle has been withdrawn, which in turn appears to depend on the degree of the disturbance. The duplication of layers of periostracum and prismatic substance, but particularly the former, gives the appearance of a dark band on the shell, which is the so-called growth ring. These authors suggest that this ring might be better termed duplication ring, or interruption ring. They also found that the annual rings which are associated with the cessation of growth in the winter season are actually formed by repeated startings and stoppings of growth, in both the late fall and early spring, due to the passing warm and cold spells, so that the annual rings thus produced are usually broad, compound rings, quite different from the single narrower interruption rings resulting from more temporary disturbances of growth. Grier (1922) used the rings of certain Ohio species to check the age of his specimens in a study of relative rates of growth of various lake species.

It is evident then that the various writers agree that the rings in the shells of fresh-water mussels are caused by cessation in growth and that the rings formed during the winter period are, in the main, heavier and better marked. It remains, therefore, in the application of these rings to a study of annual growth, to devise a method by means of which the annual rings--that is, those rings formed by the cessation of the major period of annual growth—may be differentiated from the lesser lines produced by temporary cessation of growth due to temporary unfavorable conditions.

In the case of many species of fresh-water mussels, particularly many members of the *Lampsilinæ* and other comparatively thin-shelled species, the growth interruption rings developed from all causes are partially apparent to the unaided eye. Illumination of the shells, obtained by placing an incandescent bulb immediately behind one valve of the shell, was used with considerable success in the earlier work on the light-colored yellow sand shells and Lake Pepin muckets. Such illumination brings out the full extent of each ring and was of great aid in separating the more conspicuous annual rings.

An improvement was made later by using monochromatic yellow light, in the place of ordinary light, for the illumination of the shells. The single valve was placed on a plate of monochromatic yellow glass (Corning glass, No. G38–H) through which the light from an incandescent bulb was passed. This yellow light was found to be particularly effective in bringing out the rings in the thinner-shelled species. Some of the shells were placed in front of a powerful ultra-violet light. The ultra-violet rays caused the calcium in the shell to floresce with a yellow-green light which caused the thicker annual rings to stand out sharply in contrast. The use of ultra-violet rays was found quite effective in differentiating the annual rings in even thick shells of the *Quadrula* group (results to be given in another paper), but for the shells used in the present studies, the monochromatic yellow light was found amply satisfactory.

In addition to the measurement of length—that is, the greatest antero-posterior distance measured as a chord and bounded by the ring under consideration—weight was taken and thickness determined in several series. When weights were to be taken, the shells were first heated in an electric oven to a temperature of 95° to 105° C. for an hour before the actual weighings were made. The readings were taken to the nearest 0.1 gram. In the case of weight determinations, only left valves were used for the sake of uniformity, as the two valves are not quite the same weight, owing to the differences in the teeth along the hinge margin. Thickness determinations were made by means of steel bow calipers, operated with a milled screw. As the females are readily distinguishable in the species of *Lampsilis* by the greater convexity of the shell in front of the posterior ridge and by the more or less inflated character of the posterior outline of the shell, the females and males have been considered separately. Owing to the small number of specimens of *Unio popei* Lea and *Tritogonia verrucosa* (Rafinesque) used, no separation of the sexes was made in these species.

MATERIAL

In the present studies two species—the yellow sand shell, *Lampsilis anodontoides* (Lea), and the Lake Pepin mucket, *Lampsilis siliquoidea pepinensis* Baker (*Lampsilis luteola* of authors)—have been given particular consideration because of their commercial importance. In addition, the buckhorn, *Tritogonia verrucosa* (Rafinesque) or *Tritogonia tuberculata* of authors, and Pope's purple, *Unio popei* Lea, were used for certain comparisons. In all, 1,107 specimens were examined. Of these, 600 were Lake Pepin muckets, 484 yellow sand shells, 16 buckhorns, and 7 Pope's purple.

INDIVIDUAL SPECIES

YELLOW SAND SHELL

The yellow sand shell, *Lampsilis anodontoides* (Lea), perhaps the most valuable single species of fresh-water mussel in North American waters, is found throughout the Mississippi River drainage system, with the possible exception of the upper Missouri. Simpson (1914) also records the species as occurring in the entire Gulfwise drainage area from Withlacoochee River, Fla., to the Rio Grande, and south into old Mexico. It is usually found on sandy bottoms in the larger rivers of its range but may also occur in the quieter portions of these streams on mud bottoms.

In the present studies, shells from three localities—the Mississippi River, at Fairport, Iowa; the White River, at Newport, Ark.; and the lower Rio Grande, near Mercedes, Tex.—representing the northern, middle, and southern portions of the range of this species, have been examined. In all three localities the shells are commonly taken in sufficient quantities for commercial use.

Fertilization of the eggs in the northern waters takes place during the later half of summer. The glochidia are developed by fall and are held in the marsupia until the following spring or early summer. Breeding seasons occasionally overlap. (See Lefevre and Curtis, 1912; and Coker, Shira, Clark, and Howard, 1921.) The ripe glochidia are extruded, and their parasitic stage begins some time in May or June. As their parasitic stage is usually completed in three weeks or less in northern waters, the free existence of the juvenile mussel probably begins about the first of July. This cycle gives a period of three or four months before the onset of cold weather and the formation of the first large interruption or growth ring. This period of growth for the first season is probably of 5 months' duration in Arkansas and possibly 7½ months in southern Texas. The respective durations of the growing season after the first year are estimated at 5 months in Iowa, 7 in Arkansas, and 9 in southern Texas.

The shells from the Mississippi River, at Fairport, Iowa, represented two independent collections. The first of these consisted of 100 valves from female mussels and 100 from males, as obtained from local shellers in the summer of 1926. These valves were not paired. This collection was used for growth in length determinations. The second Mississippi collection was obtained by local shellers in 1927, 1928, and 1929 and consisted of 50 left valves from female mussels and 50 from males. These shells were used for growth in weight determinations.

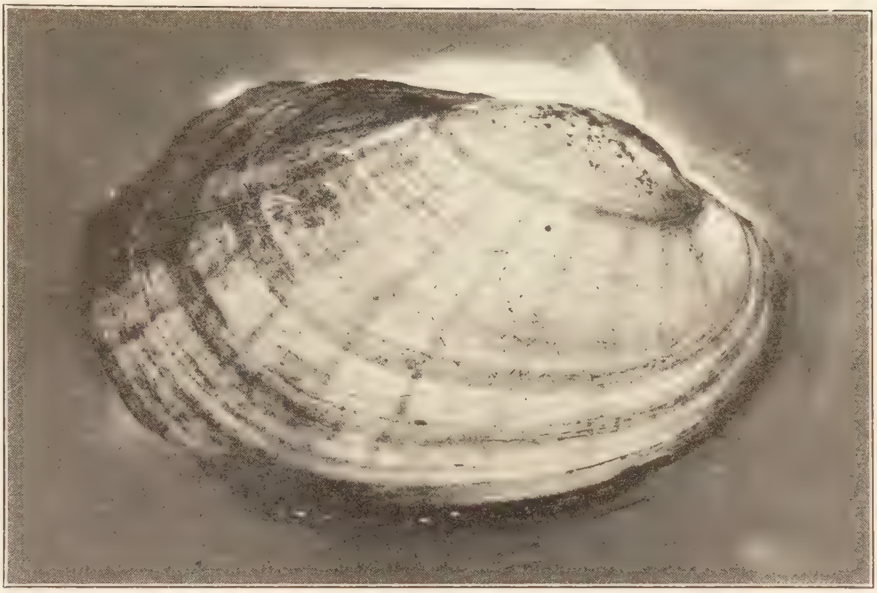

FIGURE 1.—Right valve, 7.73 centimeters in length, of a 7-year-old Lake Pepin mucket, *Lampsilis silquoidea pepinensis* Baker (*Lampsilis luteola*, of authors), illuminated to show major interruption rings, *i. e.*, annual growth rings

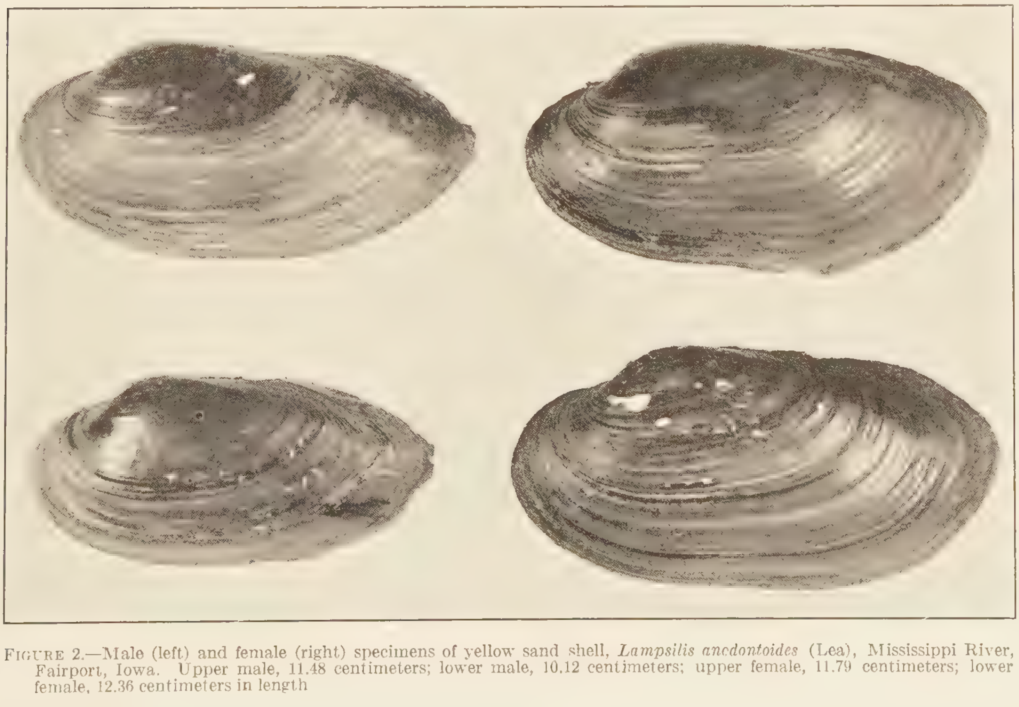

FIGURE 2.—Male (left) and female (right) specimens of yellow sand shell, *Lampsilis anodontoides* (Lea), Mississippi River, Fairport, Iowa. Upper male, 11.48 centimeters; lower male, 10.12 centimeters; upper female, 11.79 centimeters; lower female, 12.36 centimeters in length

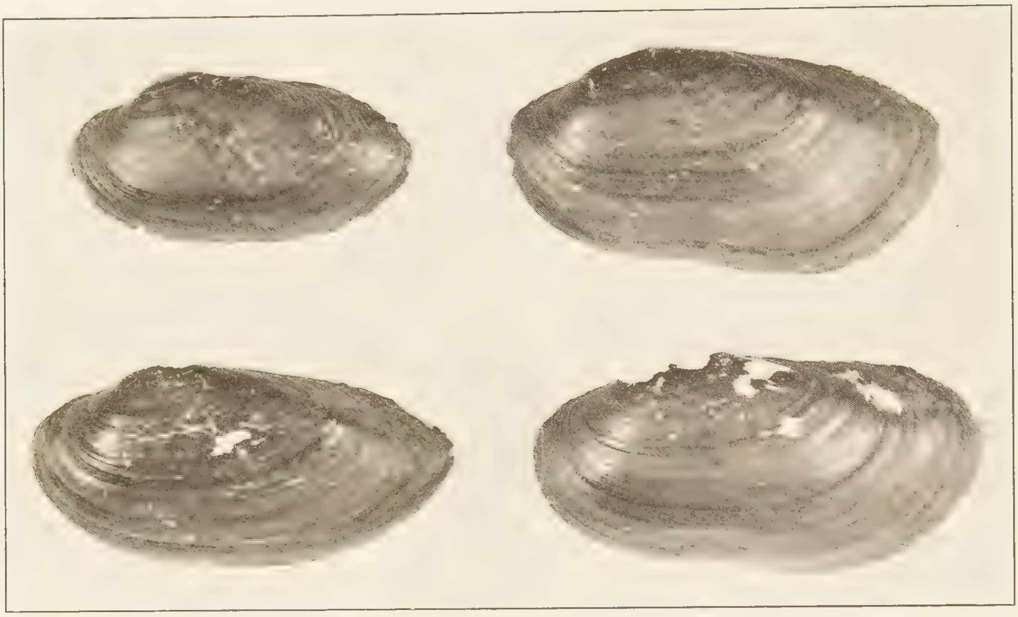

FIGURE 3.—Male (left) and female (right) specimens of yellow sand shell, *Lampsilis anodontoides* (Lea), White River, Ark. Upper male, 8.69 centimeters; lower male, 10.72 centimeters; upper female, 11 centimeters; lower female, 11.33 centimeters in length

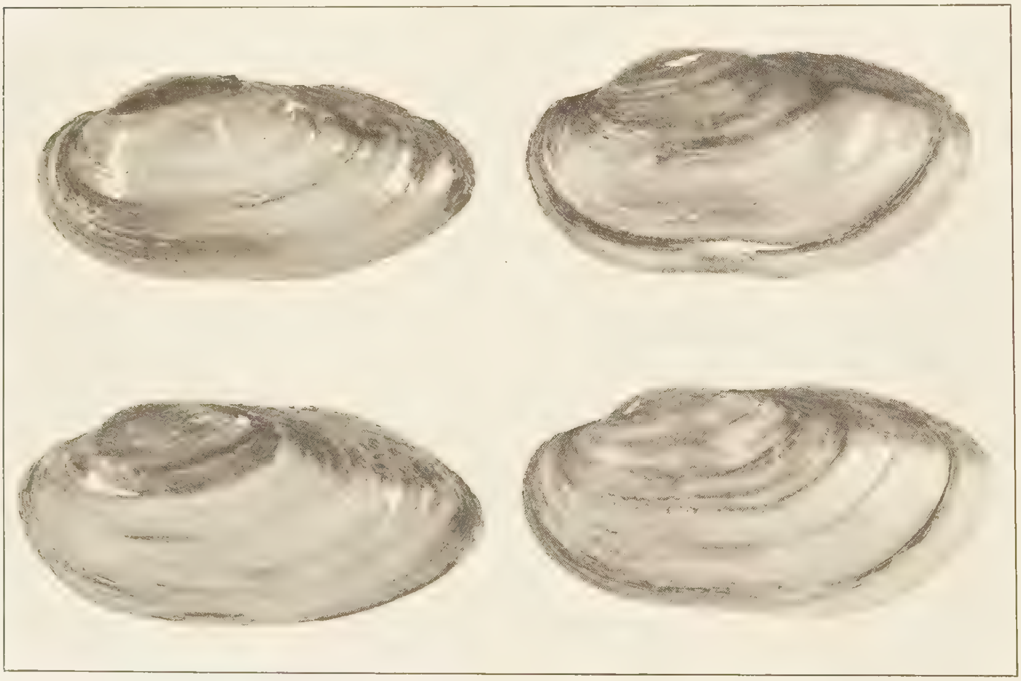

FIGURE 4.—Male (left) and female (right) specimens of yellow sand shell, *Lampsilis anodontoides* (Lea), Rio Grande Valley near Mercedes, Tex. Upper male, 11.22 centimeters; lower male, 11.89 centimeters; upper female, 11.30 centimeters; lower female, 11.93 centimeters in length

The shells from the White River of Arkansas were collected by shell buyers during the summer of 1927. The collection consisted of 50 mixed left and right valves from males and the same number from females.

The lower Rio Grande Valley shell collection was obtained from canals, settling basins, and "resacas" tributary to the Rio Grande during the winters of 1928–29 and 1929–30. This Rio Grande collection consisted of 56 shells from males and 26 from females.

LENGTH IN RELATION TO AGE

The maximum shell lengths included within each of the major interruption rings—that is, within the annual rings—having been obtained, the data were analyzed by the percentile method of Galton (1875). By inspection the 10 per cent groups seemed satisfactory for the various comparisons desired, consequently the first, fifth, and ninth decils were computed for each set of measurements. The following formula has been used throughout this work:

$$\text{Decil} = \frac{(d-F)\ i}{f} + v$$

in which d equals coefficient of decil, that is, the number of cases considered times the numerical percentage determining the decil; F, the sum of the frequencies below the class in which the coefficient of the decil is located; i, the class interval; f, the frequency of the cases within the class in which the coefficient of the decil is located; and v, the value of the lower boundary of the class in which the coefficient of the decil is located. The probable errors for the first and ninth decils were computed by the formula:

$$\text{Probable error} = \frac{0.6745\ i\sqrt{.09\ N}}{f}$$

and for the fifth decil by the formula:

$$\text{Probable error} = \frac{0.6745\ i\sqrt{N}}{2f}$$

These formulæ for the probable error can, of course, be evolved from the formulæ for standard deviation and mean probable error as currently used in statistical studies. (See Davenport, 1914.)

Using the fifth decil values from the above data, curves were drawn showing trends of growth for the yellow sand shell from the Mississippi River in Iowa, the White River in Arkansas, and the lower Rio Grande in Texas. First and ninth decils, bounding as they do the 80 per cent of the population which conformed most closely to the normal growth of the group, were also plotted. It was felt that the 10 per cent on either side of the first and ninth decils included most of the abnormal cases and errors in age determinations. At the same time it was realized that each of these two groups of extreme cases would quite likely contain true maximum and minimum deviations from the normal. As individuals of extremely rapid growth are likely to be of interest in connection with any genetic work which may be done with fresh-water mussels, in the figure showing all decils for each locality, the maximum and minimum cases for each year class have been added. These are indicated by the symbol for the locality in question, with a line drawn through it.

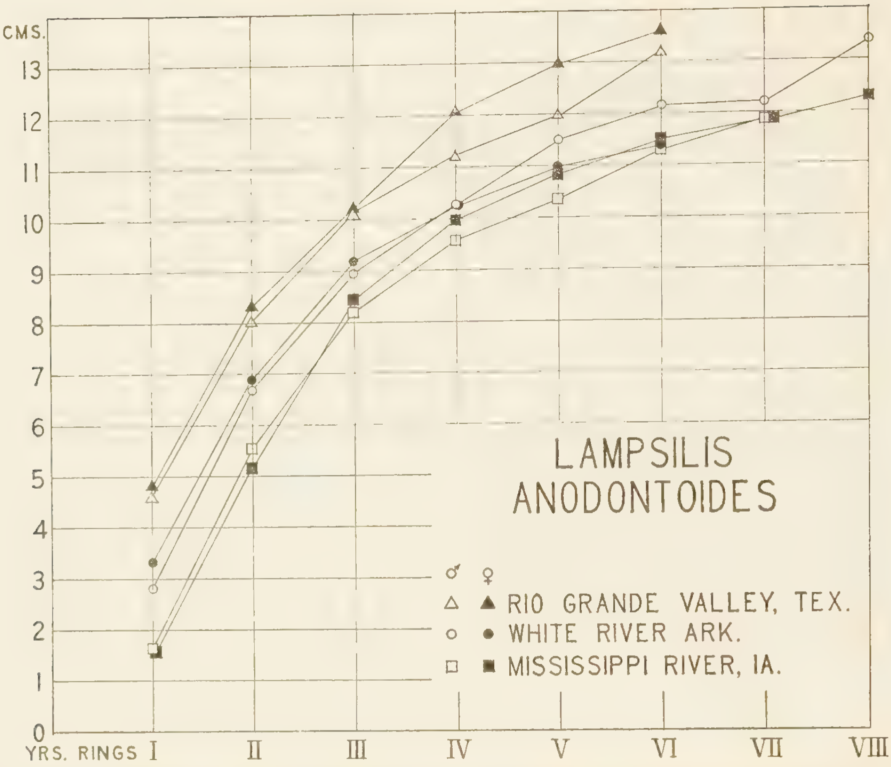

FIGURE 5.—Median curves of growth in length for both sexes of yellow sand shell, *Lampsilis anodontoides* (Lea) from the Mississippi River, Fairport, Iowa; the White River, Newport, Ark.; and the Rio Grande Valley near Mercedes, Tex. Curves obtained by plotting median values for annual length against age; that is, first year's growth precedes formation of Ring I

TABLE 1.—*Median values of length in relation to age of the yellow sand shell, Lampsilis anodontoides (Lea)*

MALES

Ring No.	Mississippi River, Iowa		White River, Ark.		Rio Grande Valley, Tex.	
	Number of specimens	Length	Number of specimens	Length	Number of specimens	Length
		Centimeters		*Centimeters*		*Centimeters*
I	100	1. 61±0. 055	50	2. 80±0. 2012	56	4. 61±0. 1079
II	100	5. 54± .067	50	6. 69± .1255	56	8. 02± .1052
III	100	8. 22± .089	40	8. 93± .0767	49	10. 11± .1072
IV	97	9. 57± .085	24	10. 26± .0970	35	11. 21± .0832
V	57	10. 38± .091	7	11. 50± .1489	6	12. 00± .3932
VI	20	11. 30± .101	4	12. 10± .1686	2	13. 26
VII	9	11. 90± .145	4	12. 2 ± .4497		
VIII			2	13. 3		

FEMALE

Ring No.	Mississippi River, Iowa		White River, Ark.		Rio Grande Valley, Tex.	
	Number of specimens	Length	Number of specimens	Length	Number of specimens	Length
I	100	1. 58±0. 059	50	3. 35±0. 1703	26	4. 80±0. 1428
II	100	5. 17± .094	50	6. 93± .1135	26	8. 33± .1320
III	100	8. 47± .073	49	9. 13± .1389	18	10. 20± .1832
IV	100	9. 96± .055	33	10. 43± .0878	5	12. 10± .1130
V	92	10. 83± .054	29	10. 97± .1067	1	13. 00
VI	33	11. 50± .108	4	11. 40± .3373	1	13. 63
VII	10	11. 90± .178				
VIII	3	12. 30± .117				

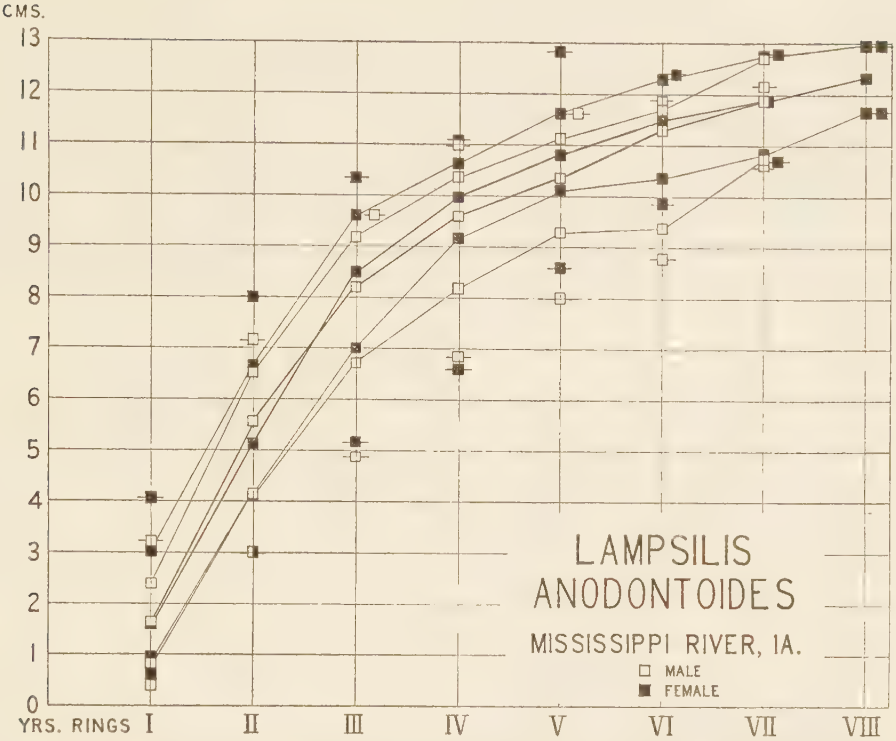

FIGURE 6.—Median curve, together with first and ninth decil curves of growth in length for both sexes of yellow sand shell, *Lampsilis anodontoides* (Lea), Mississippi River, Fairport, Iowa. Maximum and minimum cases for the various year classes are represented by the locality symbol, transfixed by a horizontal line

TABLE 2.—*Length in relation to age of yellow sand shell, Lampsilis anodontoides (Lea), Mississippi River, Iowa*

[All values in centimeters]

MALE

Ring No.	Minimum	First decil	Median	Ninth decil	Maximum
I	0.4	0.88±0.058	1.61±0.055	2.43±0.092	3.4
II	3.0	4.12± .184	5.54± .067	6.50± .081	7.2
III	4.8	6.72± .135	8.22± .089	9.20± .070	9.6
IV	6.8	8.32± .090	9.57± .085	10.36± .055	11.0
V	8.0	9.27± .152	10.38± .091	11.13± .085	11.6
VI	8.8	9.40± .452	11.30± .101	11.70± .070	11.8
VII	10.6	10.78± .304	11.90± .145	12.22± .121	12.2

FEMALE

Ring No.	Minimum	First decil	Median	Ninth decil	Maximum
I	0.6	0.94±0.052	1.58±0.059	3.00±0.337	4.6
II	.3	4.10± .107	5.17± .094	6.70± .135	8.0
III	5.2	7.00± .253	8.47± .073	9.60± .081	10.4
IV	6.6	9.20± .088	9.96± .055	10.64± .061	11.2
V	8.6	10.11± .084	10.83± .054	11.62± .149	12.8
VI	9.8	10.33± .193	11.50± .108	12.27± .097	12.4
VII	10.6	10.80± .641	11.90± .178	12.80± .160	12.8
VIII	11.6	11.66± .070	12.30± .117	12.94± .070	12.8

Figure 5 shows the median curves of growth in terms of length for the yellow sand shell as found in all three localities; and Figure 6 the growth curves for each sex of this species from the Mississippi River. It will be noted from Figure 6 that length of the individuals from the Mississippi increases very rapidly through the second year, after which a decrease in the growth rate sets in, becoming pronounced the fourth year. This rapid growth appears associated with the mussel's juvenile period, and with the coming of maturity, in the third season, the rate of increase in length steadily decreases. There is some difference in the rate of increase in length between the sexes. After the formation of the second annual ring the females take the lead in growth over the males, which up to this time have grown faster. This lead remains definite until the seventh year, when there is an indication of a mutual drawing together of the curves of growth in length of the two sexes. The males increase in rate, while the females decrease. The fact that the females do not grow quite as rapidly as the males the second year but more rapidly the third year suggests that the females do not reach maturity the second year, in as great a proportion at least, as the males. All, or a greater proportion, of the females appear to mature a year later than the males.

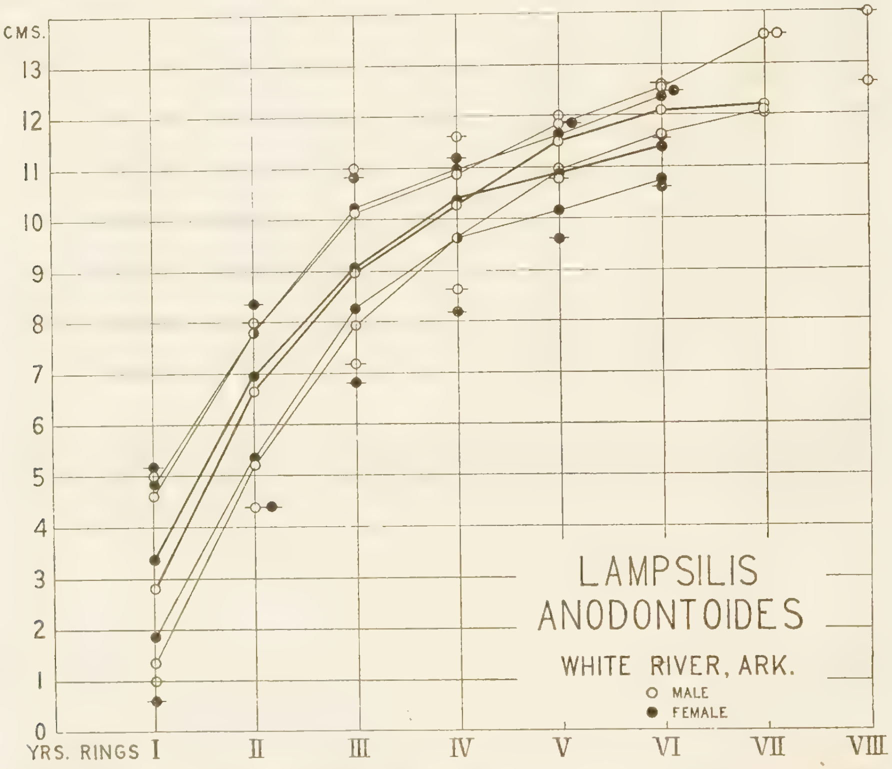

FIGURE 7.—Median curve, together with first and ninth decil curves, of growth in length for both sexes of yellow sand shell, *Lampsilis anodontoides* (Lea), White River, Newport, Ark. Maximum and minimum cases for various year classes are represented by locality symbol transfixed by a horizontal line

Figure 7 gives the curves of growth in length for the individuals found in the White River of Arkansas. As with the Mississippi shells, length increases most rapidly during the first and second years, after which a steady decrease in rate of growth sets in. The rates of increase in length for the two sexes remain close together until the fourth year. Thereafter, a marked divergence appears for the fifth and sixth years. Unlike the Mississippi River shells, the Arkansas males have the greater rate of growth in length. No specimens of females of more than 6 years of age were available in the Arkansas collection, which was unfortunate, as the marked drop in length increase for the males in the seventh year suggests that the trend of the two sexes might be toward each other, as in the case of the Mississippi shells, although the location of the 8-year class suggests a new trend for the males in extreme age.

TABLE 3.—*Length in relation to age of yellow sand shell, Lampilis anodontoides (Lea), White River, Ark.*

[All values in centimeters]

MALE

Ring No.	Minimum	First decil	Median	Ninth decil	Maximum
I	1.0	1.27±0.1192	2.80±0.2012	4.60±0.1589	5.0
II	4.4	5.20± .1589	6.69± .1255	7.80± .1192	8.0
III	7.2	7.90± .1275	8.93± .0767	10.10± .1594	11.0
IV	8.6	9.64± .1102	10.26± .0970	10.88± .1983	11.6
V	10.8	10.94± .1776	11.50± .1489	11.86± .1332	11.8
VI	11.6	11.68± .1349	12.10± .1686	12.52± .1349	12.4
VII	12.0	12.08± .1398	12.2 ± .4497	13.52± .4195	13.4
VIII		[1] 12.6		[1] 14.0	
FEMALE					
I	0.6	1.88±0.1589	3.35±0.1703	4.85±0.1430	5.2
II	4.4	5.27± .1787	6.93± .1135	7.78± .0670	8.4
III	6.8	8.26± .1342	9.13± .1389	10.27± .1175	10.8
IV	8.2	9.66± .0726	10.43± .0878	10.99± .0715	11.2
V	9.6	10.13± .0987	10.97± .1067	11.61± .1207	12.0
VI	10.6	10.22± .4047	11.40± .3373	12.32± .4047	12.2

[1] One individual.

Coker, Shira, Clark, and Howard (1921), give some figures on the lengths of 40 specimens of yellow sand shell from the St. Francis River, Ark., which they studied. Ages were determined from the growth rings. Their figures are of interest in comparison with those obtained in these studies. They state that they found 3-year-old specimens about 4 inches (10.16 centimeters) long. This compares with the median length for the White River shells, averaging males and females, obtained in these studies of 9.03 centimeters. Four-year-old specimens, they state, were 4 to 4½ inches (10.16 to 11.43 centimeters). The corresponding figure in these studies is 10.35 centimeters. For 5-year shells they give no figure, but 5-inch (12.7 centimeters) shells, they state, are 6 or more years of age. The median length of the 6-year-old shells from the White River is 11.75 centimeters.

In Figure 8 the curves of growth in length for the specimens from the lower Rio Grande Valley may be seen.

In the lower Rio Grande Valley the growth in length during the first year is very great, but thereafter there is a decline in the growth rate. The sexes diverge in rate after the third year, with a marked separation the following year. There is a suggestion that the curves for the sexes tend to approach each other after the fifth year, but since only one female over 4 years old was available, this can not be established definitely with the material at hand.

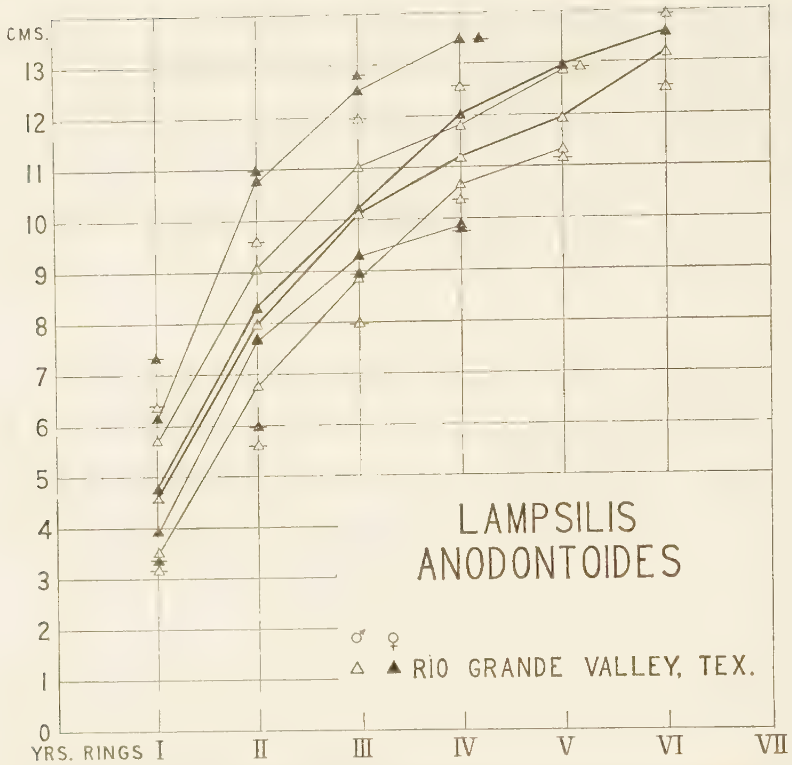

FIGURE 8.—Median curve, together with first and ninth decil curves, of growth in length for both sexes of the yellow sand shell, Rio Grande Valley, near Mercedes, Tex. Maximum and minimum cases for the various year classes are represented by the locality symbol transfixed with a horizontal line

TABLE 4.—*Length in relation to age of yellow sand shell, Lampsilis anodontoides (Lea), Rio Grande Valley, Tex.*

[All values in centimeters]

Ring No.	Minimum	First decil	Median	Ninth decil	Maximum
MALE					
I	3.2	3.52±0.0944	4.61±0.1079	5.69±0.0944	6.4
II	5.6	6.76± .2496	8.02± .1052	9.09± .0944	9.6
III	8.0	8.99± .0951	10.11± .1072	11.03± .0405	12.0
IV	10.4	10.67± .1103	11.21± .0832	11.85± .8863	12.6
V	11.2	11.32± .2496	12.00± .3932	12.88± .1568	12.8
VI		[1] 12.54		[1] 13.97	
FEMALE					
I	3.4	3.91±0.1710	4.80±0.1428	6.14±0.1710	7.4
II	6.0	7.72± .1001	8.33± .1320	10.84± .1710	11.0
III	9.0	9.36± .1685	10.20± .1832	12.60± .2964	12.8
IV	9.8	9.90± .4519	12.10± .1130	13.50± .4519	13.4
V			[1] 13.00		
VI			[1] 13.63		

[1] One individual.

Returning to Figure 5, which contains the median curves for increase in length for the species as found in all three localities, the differences in rate of increase in length become apparent. The actual values are given in Table 4. The essential difference lies in the fact that in the most southern of the three localities, the Rio

Grande Valley, growth in length is very much the greatest for any year class. Following as second in growth rate are the shells from the mid range of the species—the White River, Ark.—while those from the Mississippi in Iowa, made the slowest gains. This is true not only of the length gains but also to a large extent of the gains in weight and thickness.

A study of the extent of growth in length for the different years brings out some interesting characteristics of the different localities. In both the Mississippi and White River shells, the amount of increase in length the second year is as great, or even greater, than that shown in the first year. A decline begins the third year, which is apparently associated with sexual maturity. In the case of the Rio Grande shells on the other hand, not only is there very much greater growth the first year than in other years, but the decline in rate begins the second year. It is suggested that these Texas mussels mature a year earlier than the northern forms, but no definite data are on hand regarding this point. It is common knowledge that the growth rate of many organisms declines on reaching sexual maturity. Since the Texas mussels may possibly reach maturity a year earlier than the northern forms, the slump in growth rate begins that much sooner; but apparently the advantages gained by the greater juvenile growth, in part at least, are maintained throughout life. Figure 9 shows the relative annual growth for the species in the three localities; not only for each year, but also for periods of the year during which growth takes place in each locality. The point at which decline in growth rate begins is clearly brought out. The growing season increases progressively in length from the northern to the southern limits of the range. To this fact must be added the statement that the first season of growth for fresh-water mussels is also their shortest. In Iowa and northward the close of the parasitic period—that is, the beginning of free existence when actual growth starts—may come as late as July for the yellow sand shell. The cooling of the water with the approach of winter, may stop shell growth in September. In other words, an estimated average period of growth for this species in this locality during the first year is only 3 months. In Arkansas, the corresponding period may be 5 months; and in southern Texas, possibly 7½ months. The greater length of the growing season during the first year gives the shells from the more southern localities a pronounced gain in linear growth; but the earlier approach of maturity, which is also apparently correlated with the southern habitat, may, however, partially discount this advantage.

The variations in rate of growth in length between the sexes for the species in the different localities may be compared. In all three localities, males and females remain at about the same corresponding length until after the formation of the third ring. At this time, the shells are beginning to take on pronounced secondary sexual characteristics, which are brought out by the measurements. It is noticed that at the time of the formation of the third ring, the females of all three localities are slightly longer. This excess in length of the females also holds in the first and second years in the case of the shells from the White River and the Rio Grande. In the case of the Mississippi shells, the males exceed the females during these first two years. After the third year, and apparently associated with the species period of maximum sexual activity, pronounced and characteristic differences in growth between the sexes appear. With the approach of old age and lessened sex activity, these differences in increase in length tend to diminish, and a tendency in both sexes toward an equal length for a given age seems to be discernable.

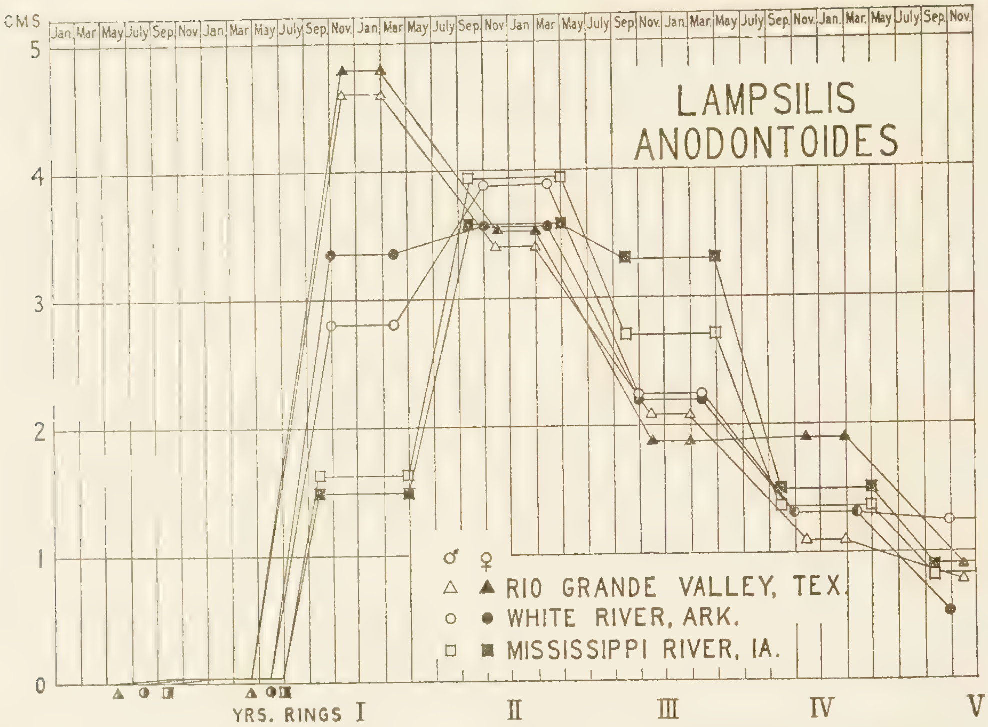

FIGURE 9.—Curves of annual growth in length, showing seasons of growth and rest of yellow sand shell at Mississippi River, Fairport, Iowa; White River, Newport, Ark.; and Rio Grande Valley near Mercedes, Tex. Increase in size; that is, growth values are actual; resting periods estimated on basis of geographic location and length of cold season as shown by Weather Bureau

TABLE 5.—*Increase in length per month of growth for each year of yellow sand shell, Lampsilis anodontoides (Lea)*

[Growing periods estimated]

Year	Mississippi River, Iowa			White River, Ark.			Rio Grande Valley, Tex.		
	Length of growing season	Male	Female	Length of growing season	Male	Female	Length of growing season	Male	Female
	Months	*Cm.*	*Cm.*	*Months*	*Cm.*	*Cm.*	*Months*	*Cm.*	*Cm.*
Glochidial year [1]	2	0.01	0.01	2	0.01	0.01	2	0.01	0.01
I	3	.53	.52	5	.56	.67	7½	.61	.64
II	5	.79	.72	7	.56	.51	9	.38	.39
III	5	.54	.66	7	.32	.31	9	.23	.21
IV	5	.27	.30	7	.19	.19	9	.12	.21
V	5	.16	.17	7	.18	.08	9	.09	.10
VI	5	.18	.13	7	.09	.06	9	.14	.07
VII	5	.12	.08	7	.01				
VIII	5		.08	7	.16				

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[1] See Merrick, 1930.

TABLE 6.—*Annual increase in length of yellow sand shell*

Locality and increase	Year ring							
	I	II	III	IV	V	VI	VII	VIII
MISSISSIPPI RIVER, IOWA	*Cms.*	*Cms.*	*Cms.*	*Cms.*	*Cms.*	*Cms.*	*Cms.*	*Cms.*
Male, annual increase	1.61	3.93	2.68	1.35	0.81	0.92	0.60	--------
Female, annual increase	1.58	3.59	3.30	1.49	.87	.67	.40	0.40
Male, cumulative increase from first year	--------	3.93	6.61	7.86	8.77	9.69	10.29	--------
Female, cumulative increase from first year	--------	3.59	6.89	8.38	9.25	9.92	10.32	10.72
WHITE RIVER, ARK.								
Male, annual increase	2.80	3.89	2.24	1.33	1.24	.60	.10	1.10
Female, annual increase	3.35	3.58	2.20	1.30	.54	.43	--------	--------
Male, cumulative increase from first year	--------	3.89	6.13	7.46	8.70	9.30	9.40	10.50
Female, cumulative increase from first year	--------	3.58	5.78	7.08	7.62	8.05	--------	--------
RIO GRANDE VALLEY, TEX.								
Male, annual increase	4.61	3.41	2.09	1.10	.79	1.26	--------	--------
Female, annual increase	4.80	3.53	1.87	1.90	.90	.63	--------	--------
Male, cumulative increase from first year	--------	3.41	5.50	6.60	7.39	8.65	--------	--------
Female, cumulative increase from first year	--------	3.53	5.40	7.30	8.20	8.82	--------	--------

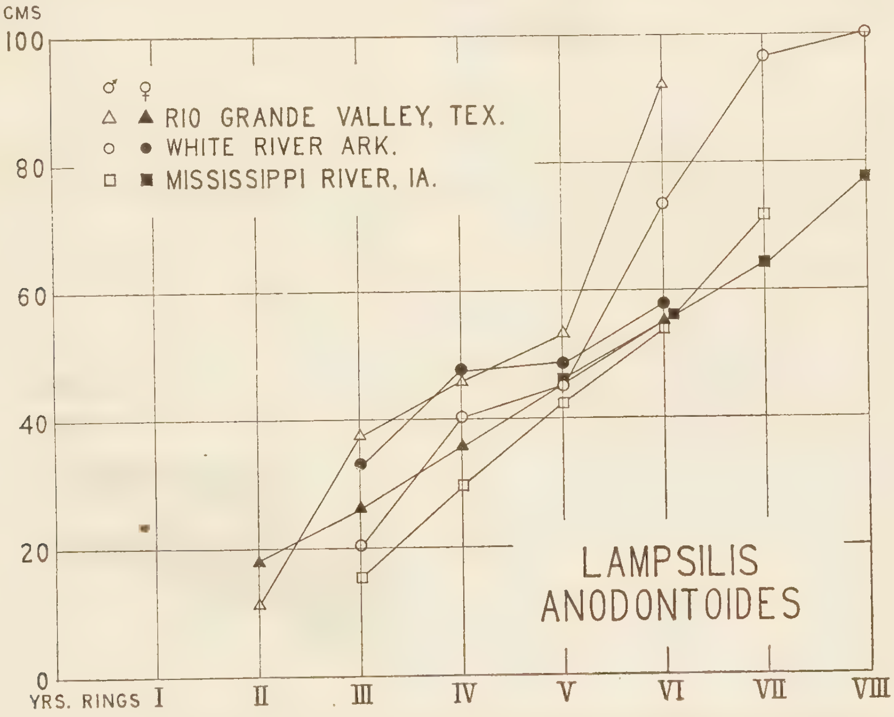

FIGURE 10.—Mean weight of left valves for year classes of yellow sand shell, Mississippi River, Fairport, Iowa; White River, Newport, Ark.; and the Rio Grande Valley near Mercedes, Tex. Weight plotted against age

WEIGHT IN RELATION TO AGE

Figure 10 shows the mean weights for the different year classes of the left valves of both sexes of the yellow sand shell from the three localities. Actual values are given in Table 7. Since only a single weight was taken from each valve, while several length values may be taken, there is a much more limited range to the weight values than to the length values. However the weight values obtained seem sufficient to indicate the essential differences in annual weight gains made by this species in the three localities.

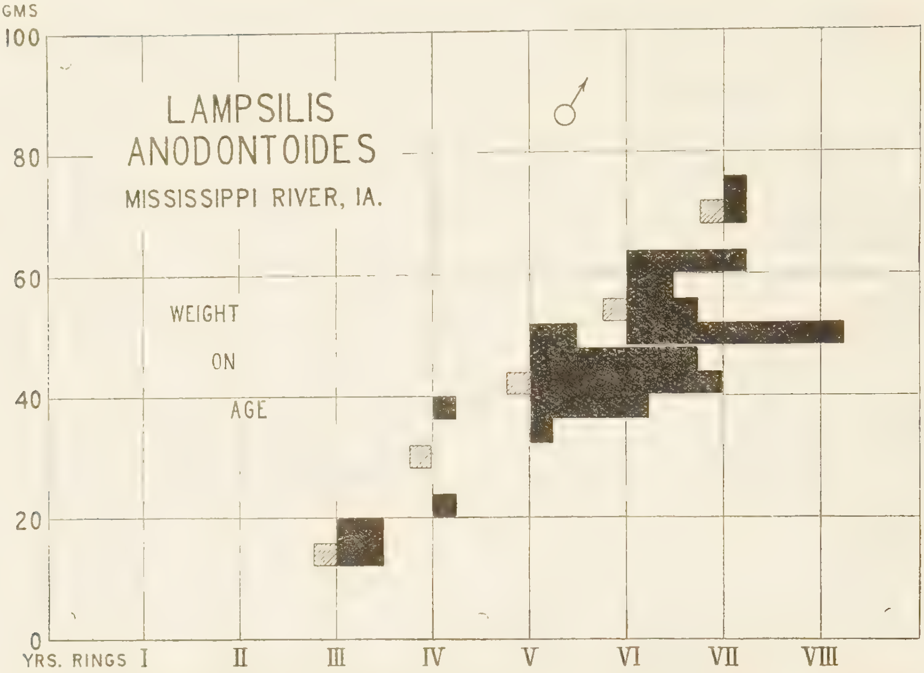

FIGURE 11.—Bar graph showing weight plotted against age for individual left valves of shells of male yellow sand shells, Fairport, Iowa. Weight values of individual left valves indicated by black squares at right of year classes. Mean weight valves shown by striated squares to left of respective year classes

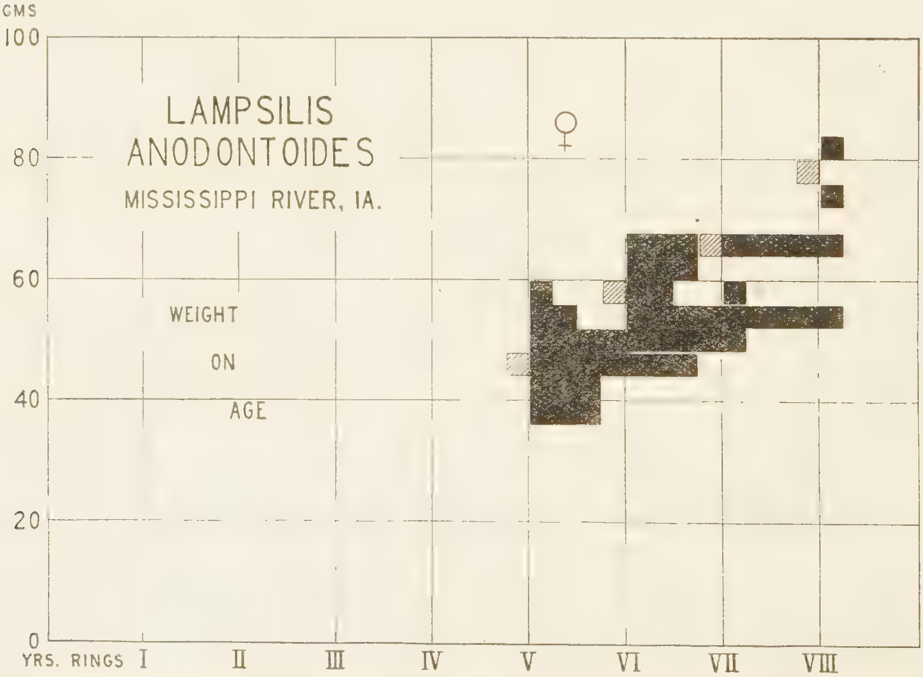

FIGURE 12.—Bar graph showing weight plotted against age for individual left valves of shells of female yellow sand shells at Fairport, Iowa. Weight values of individual left valves indicated by black squares at right of year classes. Mean weight values shown by striated squares to left of respective year classes

Before comparing the weights of the shells for the three localities, attention is called to Figures 11 and 12, which give the mean weights for males and females, respectively. The weights of individual valves are shown by the black squares on the right hand side of their respective year classes, while the mean weight for each class is shown by a square with diagonal lines to the left of the year class.

TABLE 7.—*Mean weight of left valves of yellow sand shell, Lampsilis anodontoides (Lea)*

Ring No.	Mississippi River, Iowa		White River, Ark.		Rio Grande Valley, Tex.	
	Number of specimens	Weight	Number of specimens	Weight	Number of specimens	Weight
		Grams		*Grams*		*Grams*
MALE						
II					6	11.04
III	4	15.3	3	20.7	14	38.64
IV	2	29.7	8	40.5	28	43.62
V	23	42.5	5	45.1	2	53.35
VI	19	54.0	2	73.0	1	92.20
VII	2	71.5	2	96.7		
VIII			1	100.1		
FEMALE						
II					8	18.08
III			1	33.9	9	26.19
IV			6	48.0	4	38.00
V	20	46.9	15	49.0		
VI	22	56.0	2	58.2	1	57.10
VII	6	64.6				
VIII	2	77.9				

Returning to the consideration of the weight values (as shown in fig. 10 for all three localities), there seems to be a tendency toward greater weight for the males than for the females of the same age in spite of the fact that the graphs of increase in weight are much more irregular than those of increase in length, presumably as the result of the smaller number of observations made on weight. This trend toward greater weight for the males is more evident in the older shells, becoming apparent after the fifth year for the shells from the Rio Grande Valley, and after the sixth year for the shells from the Mississippi River, with the shells from the White River as intermediate between the two. It is probable that the lighter weight of the female shells may be corollated with the reproductive activities of the female; that is, the calcium and other metabolic demands of the glochidia while developing from the eggs.

If the weight and length of the shells be considered together, the shells from the Rio Grande Valley are found to be definitely lighter for any given length than the shells from either the Mississippi in Iowa, or the White River in Arkansas. This is particularly true of the females from the Rio Grande which have weight values in the different year classes markedly lower than those of either sex from either of the other two localities. Commercially, the button manufacturers reject the smaller yellow sand shells from the Rio Grande Valley as being too thin for use, but accept those of the same linear dimensions from the White and Mississippi Rivers. This fact is readily understood when it is remembered that the 2, 3, and 4 year old shells from the Rio Grande district are definitely longer than shells of the same ages from either the White or Mississippi Rivers. The rapid growth in length made by the Rio Grande shells seems to be made in part, at least, at the expense of gains in shell weight.

The manufacturers agree that shells which have just reached a "fair commercial size" are the most satisfactory for use in the production of buttons. The smaller shells, if they be large enough to justify handling and the general overhead of production, are more valuable than the larger shells, which are likely to be more difficult to cut without chipping, and which yield blanks so thick that considerable grinding down is required. As the term "fair commercial size" is relative, an effort has been made to define this size for purposes of comparison. In view of various observations made by the manufacturers themselves, the fair commercial size for the yellow sand shell seems to be a shell about 10.5 centimeters (approximately 4 inches) in length, with a thickness at a point on the pallial line (v. i.) of 0.30 centimeters (0.12 inches, or about 5 lignes), and weighing 42 grams (about 1⅓ ounces). With this somewhat arbitrarily defined size as a standard, Table 9 has been prepared to determine the time required in each of the three localities for the yellow sand shell to reach a fair commercial size. At Fairport, Iowa, both males and females required 5 years or more; at Newport, Ark., only 4; while in the Rio Grande Valley, the males attained this size in 3 years, while the females required 4 because of their greater thinness of shell. Figure 13 shows the weight values with sex for the various year classes of the Mississippi specimens of the species for which weight values were taken, imposed on length. Actual values are given in Table 8.

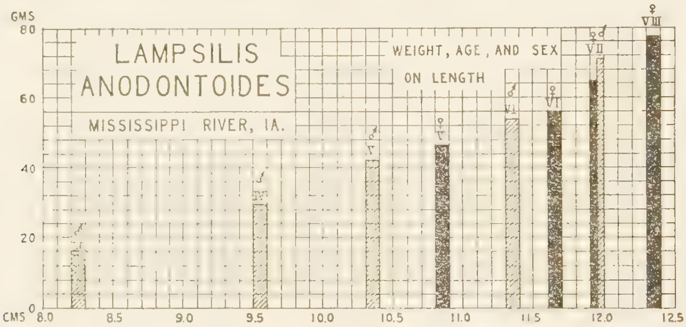

FIGURE 13.—Bar graph showing weight, sex, and age plotted against length, for yellow sand shell at Fairport, Iowa

THICKNESS IN RELATION TO AGE

The thickness of the shells of the various year classes from each locality was measured. For the sake of uniformity, this measurement was taken at a corresponding point on each specimen; namely, immediately dorsal to the pallial line on a line at right angles to the long axis of the shell, passing from the umbo across the shell. Thickness was measured with a pair of steel bow calipers with screw adjustment.

TABLE 8.—*Weight, age, and sex in relation to length of yellow sand shell, Lampsilis anodontoides (Lea), in Mississippi River, Iowa*

Ring	Length	Weight	Sex	Ring	Length	Weight	Sex
	Centimeters	*Grams*			*Centimeters*	*Grams*	
III	8.22	15.3	Male.	VI	11.50	56.0	Female.
IV	9.57	29.7	Do.	VII	11.90	71.5	Male.
V	10.38	42.5	Do.	VII	11.90	64.6	Female.
V	10.83	46.9	Female.	VIII	12.30	77.9	Do.
VI	11.30	54.0	Male.				

TABLE 9.—*Increase in length, weight, and thickness of yellow sand shell, Lampsilis anodontoides (Lea)*

Annual ring	Male						Female					
	Length		Weight		Thickness		Length		Weight		Thickness	
	Centimeters	*Per cent*	*Grams*	*Per cent*	*Centimeters*	*Per cent*	*Centimeters*	*Per cent*	*Grams*	*Per cent*	*Centimeters*	*Per cent*
MISSISSIPPI RIVER, IOWA												
I	1.61	15					1.58	15				
II	3.93	53					3.59	49				
III	2.68	78	15.3	36	0.25	83	3.30	81				
IV	1.35	91	29.7	71	.35	117	1.49	95				
V	.81	99	42.5	101	.40	133	.87	103	46.9	112	0.45	150
Total	10.38						10.83					
WHITE RIVER, ARK.												
I	2.80	27					3.35	32				
II	3.89	64					3.58	66				
III	2.24	85	20.7	49	0.30	100	2.20	87	33.9	81	0.35	117
IV	1.33	98	40.5	96	.40	133	1.30	99	48.0	114	.40	133
V	1.24	110	45.1	107	.45	150	.54	104	49.0	117	.45	150
Total	11.50						10.97					
RIO GRANDE VALLEY, TEX.												
I	4.61	44					4.80	46				
II	3.41	76	11.04	26			3.53	79	18.08	43		
III	2.09	96	38.64	92	0.30	100	1.87	97	26.19	62	0.25	83
IV	1.10	107	43.62	102	.35	117	1.90	115	38.00	90	.30	100
V	.79	114	53.55	127	.40		.90	124				
Total	12.00						13.00					

As might be expected, after the consideration of the relative weights of the shells from the three localities since thickness is in a way a function of weight, the measurements of shell thickness obtained (see Table 9) show the shells from the Mississippi River in Iowa and the White River in Arkansas to be definitely thicker than those from the lower Rio Grande Valley in Texas. The shells of the females from the Rio Grande were found to be thinner than the males of the same year class, again paralleling the weight-age data from this locality, although the females equalled or exceeded in thickness the males of the same year classes in both the White River and Mississippi River collections. It is obvious that from a commercial standpoint, the shells must not only be of a good texture and size, but must be of suitable thickness; that is, neither too thin nor excessively thick. As has been pointed out in a previous section, shells having a thickness of 0.30 centimeters or a little more, are of a desirable thickness. This thickness is attained by the females in the Rio Grande Valley and by the males and females in the White River in northern Arkansas by the end of the third year, but not until the end of the fourth year in the Mississippi at Fairport, Iowa. The annual increase in thickness in all year classes averaged about 0.05 centimeter suggesting that the rate of increase in thickness is a relatively constant factor. As, however, these measurements were taken in the region of the pallial line, these observations concerning the thickness of the shell and the annual increment of thickness can not be extended to other parts of the shell until additional data have been collected.

LAKE PEPIN MUCKET

The species, *Lampsilis siliquoidea,* (*Lampsilis siliquoidea pepinensis* Baker, *Lampsilis luteola* of authors) including all varieties, occurs, according to Baker (1928), from the Mohawk River, N. Y., west to Iowa, Kansas, and Missouri; north to Ontario, Michigan, and Minnesota; and south to Kentucky, Oklahoma, and West Virginia. It varies greatly in commercial value, the variety, *pepinensis,* as found in Lake Pepin—a widened portion of the Mississippi River between Minnesota and Wisconsin—being probably its most valuable form. Practically the same form, or a very close relative, is found in the small lakes including Cross Lake, which is connected with the Snake River, Minn., about 150 miles north of Lake Pepin.

The fish on which the Pepin mucket can pass its parasitic period include several species of spiny-rayed fishes. In other respects, the life history of the Pepin mucket is essentially the same as that of the yellow sand shell. The Pepin mucket is, however, less abundant than this last species of fresh-water mussel and ordinarily brings only about two-thirds of the market price of the yellow sand shell.

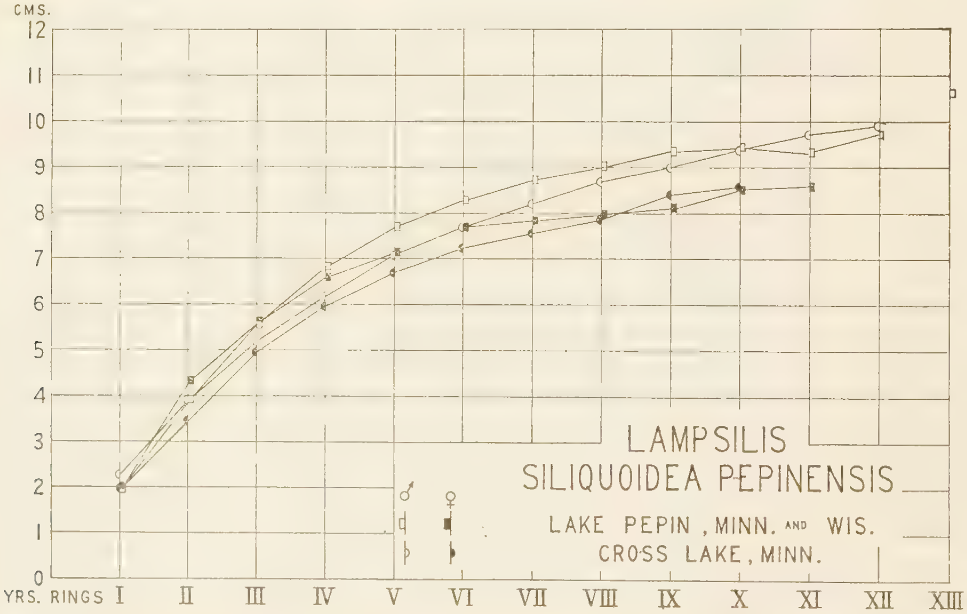

FIGURE 15.—Median curves of growth in length for both sexes of the Lake Pepin mucket. Curves obtained by plotting median values for annual length against age; that is, first year's growth precedes formation of Ring I

Two series of Lake Pepin muckets were used in the study of growth in this species. One lot was taken from Lake Pepin in the summer of 1926, and the other from Cross Lake, Minn., in 1927. Figure 15 shows the median curves for growth in length for both sexes of this species as found in each locality, and Table 10 gives the actual values. All curves are given in Figure 16, together with the location of maximum and minimum cases for each year class as found in Cross Lake. The actual values are given in Table 11.

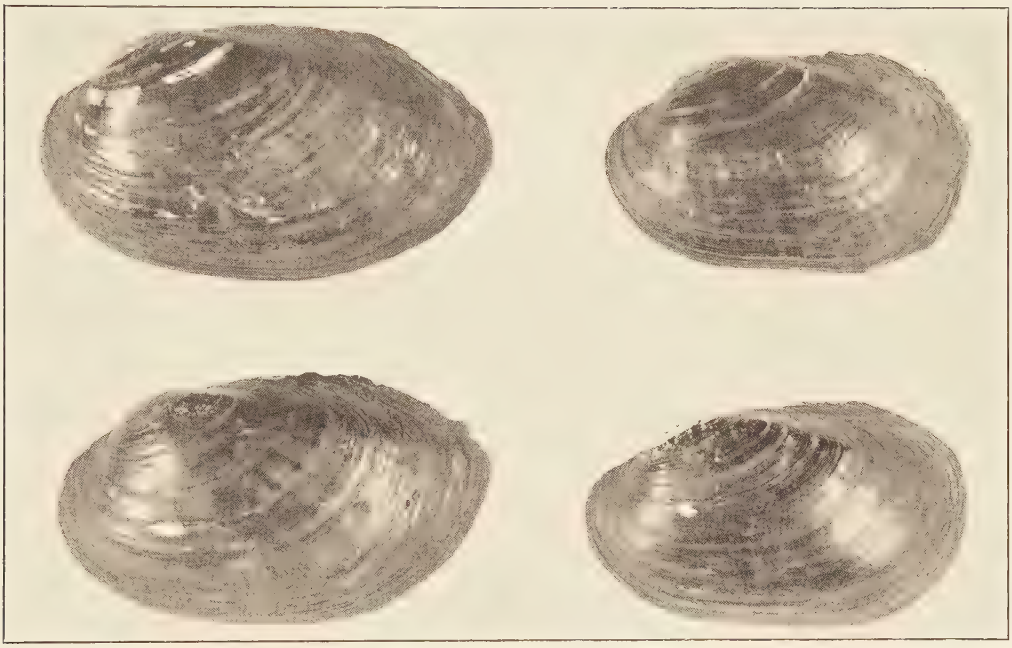

Figure 14.—Male (left) and female (right) specimens of Lake Pepin mucket, *Lampsilis siliquoides pepinensis* Baker (*Lampsilis luteola* of authors), Cross Lake, Minn. Upper male, 9.22 centimeters; lower male, 8.82 centimeters; upper female, 8.82 centimeters; lower female, 7.93 centimeters in length

TABLE 10.—*Median length in relation to age of the Lake Pepin mucket, Lampsilis siliquoidea pepinensis, Baker*

MALE

Ring No.	Lake Pepin		Cross Lake	
	Number of specimens	Length	Number of specimens	Length
		Centimeters		*Centimeters*
I	200	1.98 ± 0.048	100	2.25 ± 0.0548
II	200	3.95 ± .050	100	3.88 ± .0609
III	200	5.57 ± .054	100	5.11 ± .0527
IV	200	6.77 ± .052	100	6.17 ± .0581
V	196	7.65 ± .054	100	7.09 ± .0489
VI	185	8.31 ± .053	97	7.69 ± .0500
VII	132	8.70 ± .057	85	8.21 ± .0525
VIII	85	9.05 ± .071	60	8.72 ± .1221
IX	46	9.32 ± .091	33	9.01 ± .0742
X	25	9.43 ± .130	10	9.32 ± .1180
XI	8	9.33 ± .191	4	9.70 ± .1686
XII	3	9.70 ± .292	1	9.81 ±
XIII	1	10.60		

FEMALE

Ring No.	Lake Pepin		Cross Lake	
	Number of specimens	Length	Number of specimens	Length
I	200	1.96 ± 0.049	100	1.98 ± 0.0511
II	200	4.27 ± .042	100	3.42 ± .0535
III	200	5.66 ± .037	100	4.93 ± .0535
IV	200	6.59 ± .040	100	5.96 ± .0486
V	192	7.15 ± .034	100	6.67 ± .0456
VI	139	7.59 ± .042	100	7.24 ± .0475
VII	86	7.86 ± .050	73	7.56 ± .0564
VIII	30	7.97 ± .092	32	7.87 ± .0723
IX	17	8.10 ± .116	12	8.40 ± .1938
X	7	8.50 ± .228	2	8.55 ±
XI	1	8.60		

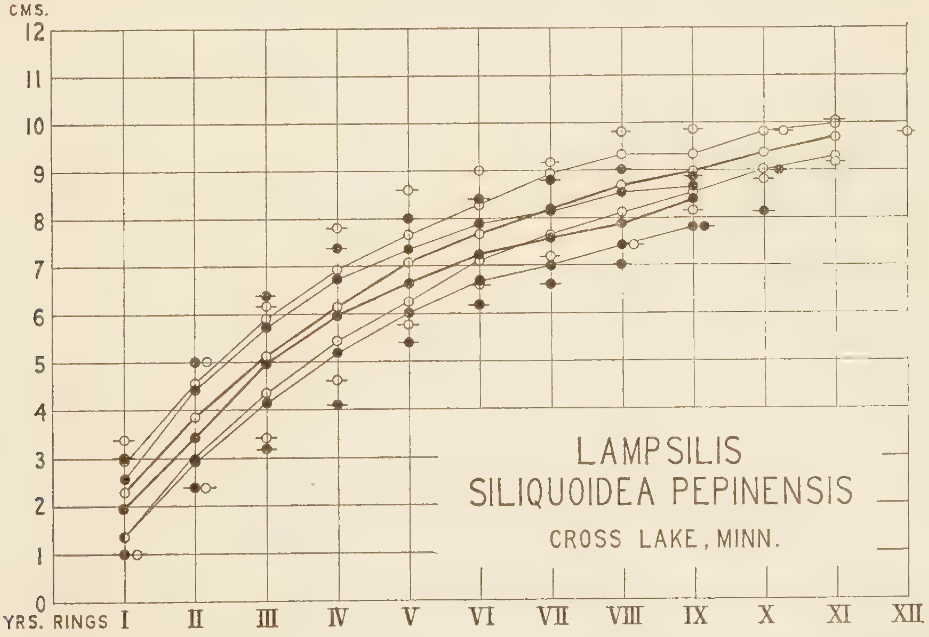

FIGURE 16.—Median curve, together with first and ninth decil curves, of growth in length for both sexes of the Lake Pepin mucket. Maximum and minimum cases for the various year classes are represented by the locality symbol transfixed by a horizontal line.

TABLE 11.—*Length in relation to age of Lake Pepin mucket, Lampsilis siliquoidea pepinensis, Baker, Cross Lake, Minn.*

[All values in centimeters]

MALE

Ring No.	Number of specimens	Minimum	First decil	Median	Ninth decil	Maximum
I	100	1.0	1.42 ± 0.0519	2.25 ± 0.0648	2.96 ± 0.0506	3.4
II	100	2.4	3.02 ± .0613	3.88 ± .0609	4.54 ± .0533	5.0
III	100	3.4	4.36 ± .0843	5.11 ± .0527	5.90 ± .0675	6.2
IV	100	4.6	5.47 ± .0749	6.17 ± .0581	6.90 ± .0636	7.8
V	100	5.8	6.25 ± .0613	7.09 ± .0489	7.65 ± .0519	8.4
VI	97	6.6	7.12 ± .0452	7.69 ± .0500	8.38 ± .0497	9.0
VII	85	7.2	7.68 ± .0443	8.21 ± .0525	8.94 ± .0601	9.2
VIII	60	7.4	8.09 ± .0742	8.72 ± .1221	9.35 ± .0616	9.8
IX	33	8.2	8.46 ± .0725	9.01 ± .0742	9.39 ± .0609	9.8
X	10	8.8	9.00 ± .0713	9.32 ± .1180	9.80 ± .0624	9.8
XI	4	9.2	9.28 ± .1349	9.70 ± .1686	9.92 ± .1349	9.8
XII	1			9.81		

FEMALE

Ring No.	Number of specimens	Minimum	First decil	Median	Ninth decil	Maximum
I	100	1.0	1.34 ± 0.0637	1.98 ± 0.0511	2.60 ± 0.0431	3.0
II	100	2.4	2.90 ± .0413	3.42 ± .0535	4.42 ± .1920	5.0
III	100	3.2	4.22 ± .0637	4.93 ± .0535	5.71 ± .0749	6.4
IV	100	4.2	5.23 ± .0612	5.96 ± .0508	6.72 ± .0685	7.4
V	100	5.4	6.03 ± .0595	6.67 ± .0456	7.31 ± .0505	8.0
VI	100	6.0	6.68 ± .0460	7.24 ± .0475	7.89 ± .0723	8.4
VII	73	6.6	7.01 ± .0443	7.56 ± .0564	8.16 ± .0523	8.8
VIII	32	7.0	7.44 ± .0637	7.87 ± .0723	8.56 ± .0882	9.0
IX	12	7.8	7.85 ± .1123	8.40 ± .1938	8.65 ± .0843	8.8
X	2		8.11	8.55	8.98	

The growth curves of the Pepin mucket are of the same general type as those of the yellow sand shell, of the buckhorn, and of Pope's purple, the major differences between these several curves being those of rate—the Pepin mucket having an appreciably slower rate of growth than its congener, the yellow sand shell. The year classes in the curves of the Pepin mucket, however, are quite suggestive in comparison with the curves of the yellow sand shell. Although no selection of individuals was made when the original collections were obtained, the year classes in the yellow sand shell groups include only the VIII-year class, with most of the individuals dropping out at the VI-year class, while the year classes of the Pepin mucket groups include the XIII-year class, with a good representation in the X and XI year classes. Shellers along the river regularly report that they do not find "mossbacks" and "old-timers" among the yellow sand shells as they do among the Pepin muckets, and examinations of various heaps of unsorted shells as collected from the river verify these statements in that yellow sand shells more than 6 years old are hard to find. No explanation of these differences in the apparent lengths of the life spans of the Pepin mucket and yellow sand shells is offered; but of the four species studied, the two slow-growing species, the Pepin mucket and the buckhorn, are both well represented in the higher year classes—that is, those above the VI-year class.

Within the species, the Pepin muckets from Lake Pepin show a slightly greater rate of growth in length than the Pepin muckets from Cross Lake. Several factors may combine to produce this difference, but it may be pointed out that Cross Lake is farther north, and that the ice is known to remain in this lake much later in the spring than in the Mississippi at Lake Pepin.

Figure 17 shows the distribution of the left valves of the Cross Lake shells in the different year classes according to weight, males in the upper portion of the chart, and females in the lower portion. Each black square represents one left valve. The mean weight for each class is indicated by the squares with diagonal lines. Actual values for the mean weights are given in Table 12. It will be noticed that not only were the males longer for each year class than the females, but they also exceed the females in weight in those year classes for which data are available.

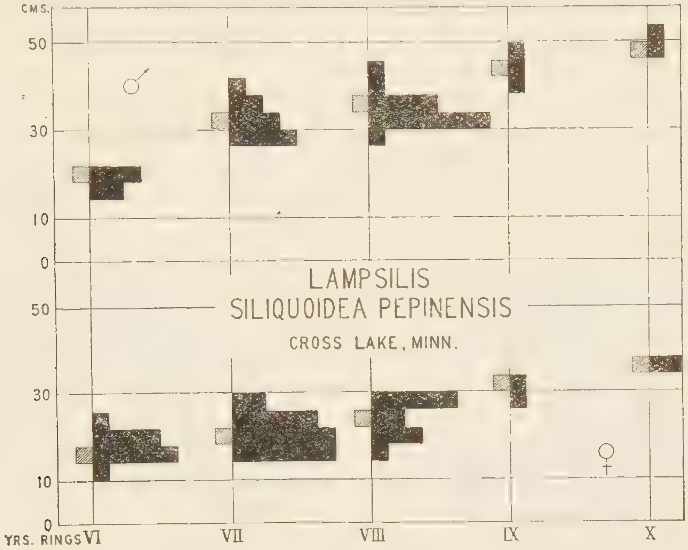

FIGURE 17.—Bar graph showing weight plotted against age for individual left valves of shells of male (above) and female (below) Lake Pepin mucket. Weight values of individual left valves indicated by black squares at right of year classes. Mean weight values shown by striated squares to left of respective year classes

TABLE 12.—*Mean weight of left valves of Lake Pepin mucket, Lampsilis siliquoidea pepinensis, Baker, Cross Lake, Minn.*

Ring No.	Male		Female	
	Number of specimens	Weight	Number of specimens	Weight
		Grams		*Grams*
VI	5	21.2	11	19.8
VII	9	25.4	19	24.3
VIII	14	28.1	11	25.9
IX	3	39.6	2	32.3
X	2	49.8	2	38.9

Coker, Shira, Clark, and Howard (1921), held six specimens of this species at the United States Bureau of Fisheries Biological Station at Fairport, Iowa, for six years. The specimens were held in ponds freshly made at the start of the investigations and kept filled with water pumped from the Mississippi River. The Fairport station is over 250 miles south of Lake Pepin which would give an appreciably longer and warmer growing season. The average length of these six specimens for each year compare very well with the lengths obtained for the Lake Pepin and Cross Lake specimens. After averaging the lengths for the two sexes for these last named localities, and comparing the lengths for each age in the following order: Fairport, Lake Pepin, and Cross Lake, the figures for the second year are 4.34, 4.11, and 3.65 centimeters respectively; for the third year, 6.88, 5.62, and 5.02; for the fourth year, 7.70, 6.68, and 6.07; for the fifth year, 8.06, 7.40, and 6.88; for the sixth year, 8.49, 7.95, and 7.47. Aside from the fact that so few specimens were available in the Fairport tests, it is believed that they check up very well with what might be expected in relation to Lake Pepin and Cross Lake individuals.

BUCKHORN AND POPE'S PURPLE

To test the applicability of the ring method to studies of growth in species belonging to other genera, 16 specimens of the buckhorn, *Tritogonia verrucosa* (Rafinesque), *Tritogonia tuberculata* of authors, from the Mississippi River at Fairport, Iowa, and 7 specimens of Pope's purple, *Unio popei* Lea, from the lower Rio Grande Valley in Texas, were weighed and measured.

The buckhorn is a heavy, comparatively slow-growing shell, ranging (Simpson, 1914) throughout the Mississippi drainage system generally, and streams tributary to the Gulf from Alabama to central Texas. This shell has some commercial value.

Pope's purple is a moderately thin, rapidly growing shell, ranging (Simpson, 1914) through southern Texas and northeastern Mexico. This species, although purple in color, has considerable commercial importance, as the shells can be bleached quite readily to a good, usable white color.

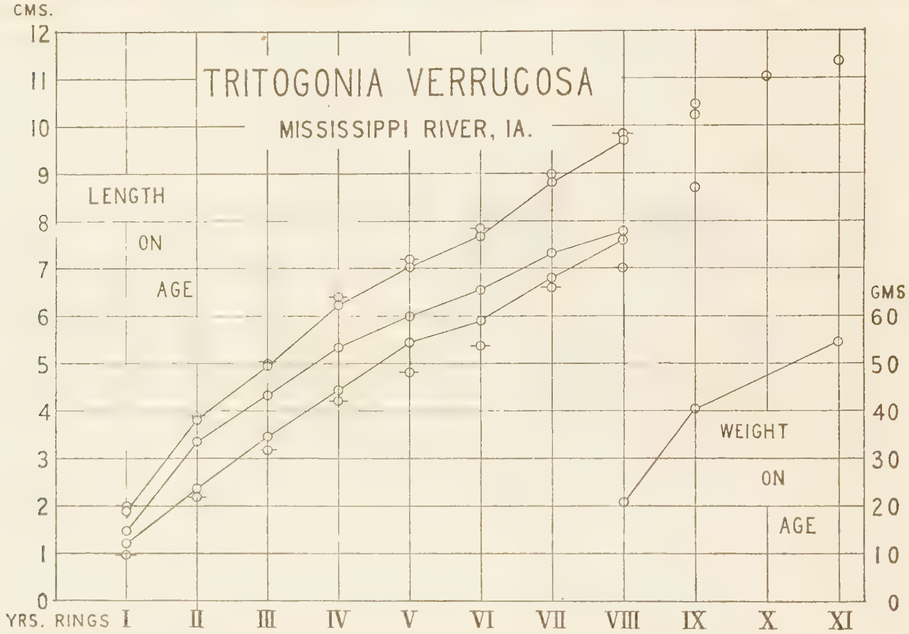

FIGURE 19.—Median curve, together with first and ninth decil curves of growth in length for the buckhorn from Fairport, Iowa. Maximum and minimum cases for various year classes are represented by the locality symbol transfixed by a horizontal line. Also curve showing mean weight on age for the eighth, ninth, and eleventh year classes

TABLE 13.—*Length in relation to age of male and female buckhorns, Tritogonia verrucosa (Rafinesque). Mississippi River, Iowa*

[All values in centimeters]

Ring No.	Number of specimens	Minimum	First decil	Median	Ninth decil	Maximum
I	16	1.0	1.23	1.49	1.88	2.0
II	16	2.2	2.32	3.35	3.77	3.8
III	16	3.2	3.48	4.35	4.94	5.0
IV	16	4.2	4.48	5.36	6.24	6.4
V	16	4.8	5.46	6.00	7.08	7.2
VI	16	5.4	5.92	6.56	7.68	7.8
VII	16	6.6	6.76	7.30	8.88	9.0
VIII	16	7.0	7.60	7.80	9.68	9.8
IX	2		8.69	9.59	10.49	
X	1			11.01		
XI	1			11.39		

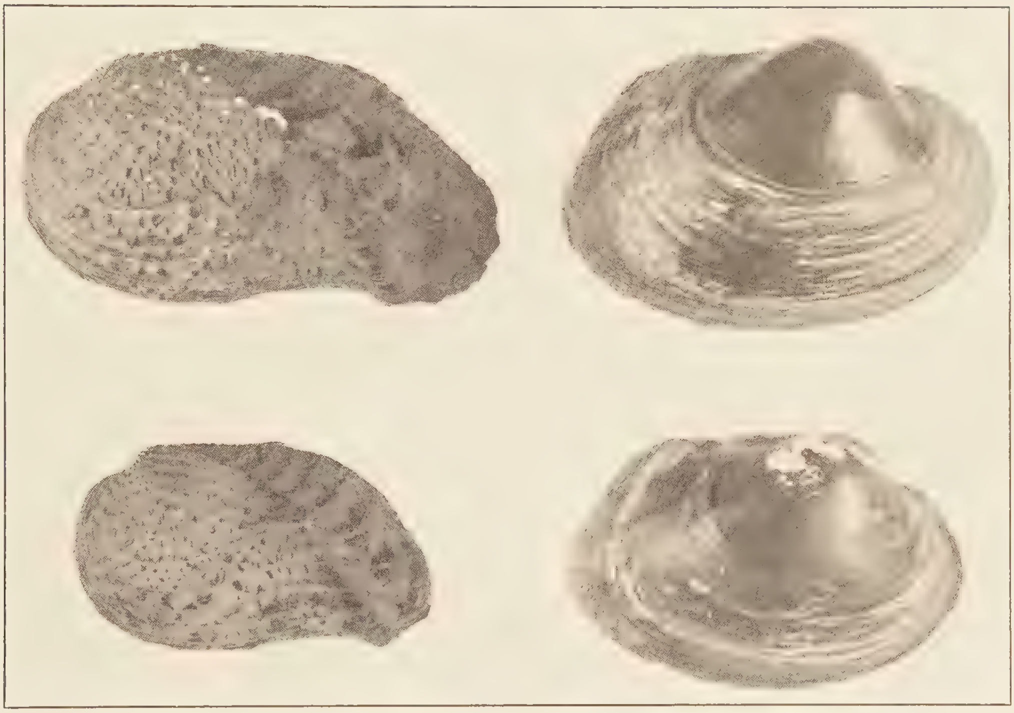

FIGURE 18.—Specimens of buckhorn, *Tritogonia verrucosa* (Rafinesque) (on left), Mississippi River, Fairport, Iowa; and Pope's purple, *Unio popei* Lea (on right), Rio Grande Valley near Mercedes, Tex. Upper buckhorn, 10.22 centimeters; lower buckhorn, 7.69 centimeters; upper purple, 9.26 centimeters; lower purple, 8.36 centimeters in length

The values obtained for these two species have been incorporated in Figure 19 and Tables 13 and 14 for the buckhorn; and Figure 20 and Table 15, for Pope's purple.

TABLE 14.—*Weight in relation to age of buckhorn, Tritogonia verrucosa (Rafinesque), Mississippi River, Iowa.*

Ring	Weight
	Grams
VIII	20. 1
IX	40. 3
X	-------
XI	54. 8

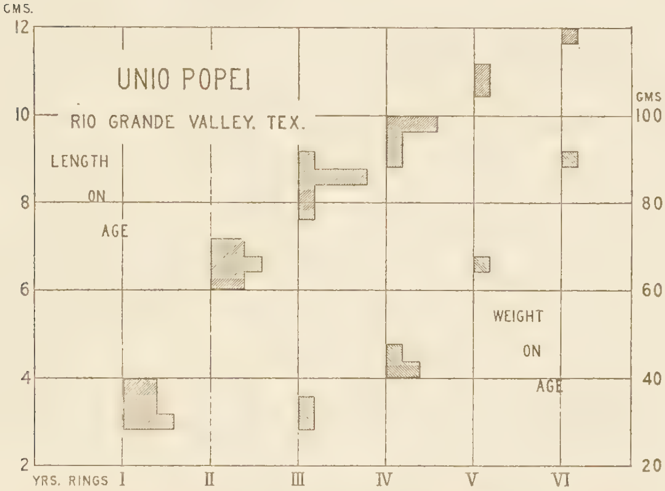

FIGURE 20.—Bar graph showing length (left) plotted against age, and weight (right) plotted against age of seven individual right valves of Pope's purple from Rio Grande near Mercedes, Tex.

TABLE 15.—*Males and females, Pope's purple, Unio popei, Lea, Rio Grande Valley, Tex.*

Age in years	Weights			Length	Height	One-half ventricosity[1]	Annual rings					
	Left valve	Right valve	Mean				I	II	III	IV	V	VI
	Grams	*Grams*		*Centimeters*	*Centimeters*	*Centimeters*						
3	31. 4	29. 9	32. 4	8. 41	5. 50	1. 91	3. 29	6. 71	8. 41	-------	-------	-------
	-------	34. 9	-------	8. 55	5. 65	1. 94	3. 66	6. 51	8. 55	-------	-------	-------
	-------	41. 3	42. 6	9. 13	6. 02	2. 01	3. 08	6. 08	7. 85	9. 13	-------	-------
4	44. 9	45. 0	-------	9. 32	6. 35	2. 19	3. 13	6. 20	8. 16	9. 32	-------	-------
	-------	41. 6	-------	9. 92	6. 95	2. 13	3. 78	6. 92	8. 62	9. 92	-------	-------
5	64. 5	64. 0	64. 0	10. 82	7. 38	2. 45	3. 05	6. 63	8. 61	9. 92	10. 82	-------
6	88. 7	89. 3	89. 3	11. 79	8. 17	2. 86	3. 52	6. 80	8. 81	9. 91	10. 70	11. 79

[1] By ventricosity is understood the greatest thickness of the two valves when closed, measurement usually falling in the umbonal region.

As it is not intended to give a detailed study of these species here, they are reviewed together. It was found that the ring method was quite as satisfactory for the study of these species as for *Lampsilis anodontoides* and *Lampsilis siliquoidea pepinensis*, and that the same type of growth curves were obtained in all cases.

Comparisons within the species show that the rate of growth of the yellow sand shell was greater in the southern and middle portions of its range than in the northern portion. If the same type of variation of growth rate holds for the buckhorn in its northern and southern ranges, the buckhorn may be listed as having the slowest growth rate of any of the four species studied, as its actual growth rate at Fairport, Iowa, was about the same as that of the Lake Pepin mucket at Cross Lake, Minn.

AREA OF SHELL

Although length, weight, and thickness furnish indices of growth from which growth curves giving the physiological aspects of the problem may be constructed, from a practical commercial standpoint the growth of the shell is measured largely by the area of the shell from which button blanks may be cut.

Since even the shells of the very flat species, as the pink heelsplitter, *Proptera alata*, are actually curved plates presenting both concave and convex surfaces, it is rather difficult to measure exactly the surface area of a mussel shell. For purposes of comparison, however, a projection was chosen, as in the cutting of blanks the shell is handled to a large extent as if it were a plane surface. Placing the valve on a piece of white paper, and tracing around its margin with a pencil, a projection of the shell was readily obtained. The area of this figure was then measured in square centimeters by tracing the outline of the projection with a planimeter.

The average values for the areas of the projections of shells from the various year classes are listed in Table 16. It is evident from this table that the surface of the yellow sand shell is greater for each year class in specimens from the southern portion of the range of this species than from the northern part. There is also a noticeable difference in area of the shell correlated with the sex of the individual.

Considering shell area alone in terms of year classes, the comparisons of the four species examined favor the rapidly growing species and the southern habitats.

TABLE 16.—*Average areas (in square centimeters) of valves by year classes*

Species	Sex	Year classes							Locality
		II	III	IV	V	VI	VIII	XI	
Yellow sand shell, Lampsilis anodontoides.	Male		23.0	28.8	40.8				Mississippi River, Fairport, Iowa.
Do	Female				41.3				Do.
Do	Male		20.7	38.0	39.1				White River, Newport, Ark.
Do	Female			40.8	46.6				Do.
Do	Male	23.9	42.3	44.8		64.2			Rio Grande, near Mercedes, Tex.
Do	Female		35.9	59.8					Do.
Lake Pepin mucket, Lampsilis siliquoidia pepinensis.	Male				19.9	24.5		38.3	Cross Lake, Minn.
Buckhorn, Tritogonia verrucosa							26.5		Mississippi River, Fairport, Iowa.
Pope's purple, Unio popei			37.4			67.2			Rio Grande, near Mercedes, Tex.

DISCUSSION

Considering all of the data obtained from over 1,100 specimens, the application of the annual-ring method to growth studies of fresh-water mussels seems both reliable and practical, judging from the uniformity of the growth curves developed from these data and the ease with which these measurements may be made on the great majority of shells.

That the shell rings are the result of an interruption of growth has been established experimentally (Lefevre and Curtis, 1912; Coker, Shira, Clark, and Howard, 1921); and that the changes in environmental conditions during the winter months provoke a major interruption of growth has been observed by various writers (Hazay, 1881; Isley, 1914). Weinland (1918) working with the European fresh-water mussel, *Anodonta cygnea*, found that the daily oxygen consumption fell from 5.3 milligrams in November to 1.7 milligrams during December, January, and February; rising again to 5.3 milligrams in March, 9.6 milligrams in April and May, and 17.0 milligrams in June. This fall in oxygen consumption during the winter months to a level only one-tenth of that maintained by the same animal during the month of June, implies metabolic changes which might readily provide a physiological basis for the winter growth interruption and account for the extent of this interruption.

Eliminating the few problematic individuals which are always found in any large series of animals, this major annual ring was rather easily differentiated from the other narrower interruption rings.

During the analysis of the data, the length was plotted against age on semilogarithmic paper to ascertain whether the growth in length in fresh-water mussels represents a logarithmic function comparable to many other biological corollaries of growth. (See Brody, 1927; Brody, Comfort, and Matthews, 1928.) In the main, up to the VI-year class, the length values from mussel shells were reducible to a straight line by this treatment. After passing the VI-year class, the gains in length were less than the logarithmic values required to maintain a straight line, indicating a more abrupt decline in growth rate than that represented by a simple logarithmic progression; that is, there was a distinct slowing of linear growth, suggesting a senile stage. (See Minot, 1908.)

Since the commercial value of the fresh-water shells decreases very rapidly beyond the VI-year class, this period of senile decline is not discussed in detail here.

As several factors, such as increase in the weight of the shell and changes in the metabolism of the older animals, may be correlated with this change in the linear growth rate of the older mussels, additional data are being collected on this phase of the problem.

SUMMARY

By means of the annual ring method, the year classes of over 1,100 fresh-water mussel shells have been determined. Studies of length, weight, and thickness were made on the shells of these groups.

Four commercial species, the yellow sand shell, *Lampsilis anodontoides;* the Lake Pepin mucket, *Lampsilis siliquoidea pepinensis;* the buckhorn, *Tritogonia verrucosa;* and Pope's purple, *Unio popei,* were used. Growth curves were developed for each of these species.

Yellow sand shells from three localities—the Mississippi River at Fairport, Iowa; the White River at Newport, Ark.; and the Rio Grande Valley, near Mercedes, Tex.—were studied. These localities represented the northern, middle, and southern portions of the range of this species.

The growth curves for length of the yellow sand shell show that the Mississippi shells made their greatest gain in length during the second year; that the White River shells made about equal gains during the first and second years; and that the Rio Grande shells made their greatest gain during the first year. After passing the maximum rate gain, the rate of gain in length declines very rapidly to the VI-year class, beyond which the gains in length are small.

By comparing the weights of the yellow sand shells from the three localities, it may be seen that the Texas shells were conspicuously lighter in proportion to their length than the shells from Arkansas and Iowa. Thickness studies emphasize this difference.

Combining the data on length, weight, and thickness, it was found that the yellow sand shell requires about 5 years to reach a fair commercial size in the Mississippi at Fairport, Iowa; 4 years in the White River, in Arkansas; and but 3 or 4 years in the lower Rio Grande.

Differences in the rates of growth of the two sexes of yellow sand shell, apparently correlated with the changes in the contour of the shell accompanying sexual maturity, were noted in each of the three localities.

Considering the commercial aspect of length, weight, and thickness, together with the age of the year class, the yellow sand shells from the White River in Arkansas made the most satisfactory growth.

Growth curves for the Pepin mucket, the buckhorn, and Pope's purple were of the same general types as those described for the yellow sand shell.

The Pepin mucket and the buckhorn grow more slowly and have longer life spans under the existing conditions in the upper Mississippi than the yellow sand shell in any part of its range as studied.

Comparisons of valve areas—that is, the surface available for the cutting of blanks from the shells of the four species studied—made on the basis of year classes, favored both the rapidly growing species and the southern habitats.

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